TRAJECTORIES OF COLLABORATIVE SCIENTIFIC CONCEPTUAL CHANGE: MIDDLE SCHOOL STUDENTS LEARNING ABOUT ECOSYSTEMS IN A CSCL ENVIRONMENT

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ABSTRACT OF THE DISSERTATION

Trajectories of Collaborative Scientific Conceptual Change: Middle School Students Learning about Ecosystems in a CSCL Environment

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The dissertation aims to achieve two goals. First, it attempts to establish a new theoretical framework – the collaborative scientific conceptual change model, which explicitly attends to social factor and epistemic practices of science, to understand conceptual change. Second, it report the findings of a classroom study to investigate how to apply this theoretical framework to examine the trajectories of collaborative scientific conceptual change in a CSCL environment and provide pedagogical implications. Two simulations were designed to help students make connections between the macroscopic substances and the aperceptual microscopic entities and underlying processes. The reported study was focused on analyzing the aggregated data from all participants and the video and audio data from twenty focal groups' collaborative activities and the process of their conceptual development in two classroom settings. Mixed quantitative and qualitative analyses were applied to analyze the video/audio data. The results found that, overall participants showed significant improvements from pretest to posttest on system understanding. Group and teacher effect as well as group variability were detected in both students' posttest performance and their collaborative activities, and variability emerged in group interaction. Multiple data analyses found that attributes of collaborative discourse and epistemic practices made a difference in student learning. Generating warranted claims in discourse as well as the predicting, coordinating theory-evidence, and modifying knowledge in epistemic practices had an impact on student's conceptual understanding. However, modifying knowledge was found negatively related to students' learning effect. The case studies show how groups differed in using the computer tools as a medium to conduct collaborative discourse and epistemic practices. Only with certain combination of discourse features and epistemic practices can the group interaction lead to successful convergent understanding. The results of the study imply that the collaborative scientific conceptual change model is an effective framework to study conceptual change and the simulation environment may mediate the development of successful collaborative interactions (including collaborative discourse and epistemic practices) that lead to collaborative scientific conceptual change.

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CHAPTER 1

INTRODUCTION

One problem in science education is that students often do not possess an in-depth conceptual understanding of science and demonstrate an inability to analyze and apply scientific thinking processes (National Research Council, 1996). The field of research in conceptual change has proliferated studies to investigate the nature and process of conceptual change and to search for theoretical underpinnings and pedagogical strategies to foster student conceptual change and improve higher-level thinking and conceptual understanding. One of the common instructional strategies is to confront students with discrepant events to help students realize the cognitive conflicts, which is widely accepted to be essential to radical conceptual change (Posner, Strike, Hewson, & Gertzog, 1982).

However other researchers propose that conceptual change is a gradual process and argue that adults, children and even trained scientists fail to make a change in their theories when they face conflicting evidence (Mason, 2003). Chinn and Brewer (2001) characterize seven different possible reactions towards anomalous data among, most of which fail to change previous theories even in the face of conflicting evidence. It indicates that cognitive conflict is not sufficient to facilitate learners on developing deep conceptual understanding and fostering conceptual change. Other facilitating factors may be required, such as peer interactions and sophisticated scientific epistemic practices. The purpose of the reported study is to: 1) propose a new model of conceptual change called collaborative scientific conceptual change model; 2) examine student collaborative scientific conceptual change process while using computer simulations to understand aquarium ecosystems through three perspectives (i.e., cognitive, social, and epistemic) included in the new conceptual change model.

Instead of focusing on cognitive conflict, a new theoretical framework - the collaborative scientific conceptual change model - is constructed and applied to explain conceptual change processes. This model stresses cognitive factors as well as the effect of social interactions and the role of epistemic practices of science. It is proposed that collaborative scientific conceptual change occurs when learners co-construct new knowledge and make a shift from their previous ways of thinking towards the scientific ways of thinking that scientists use to explain phenomena. Collaborative discourse may help students discover knowledge discrepancies and gaps through sharing ideas thus stimulating convergent conceptual change. In addition, sociocultural views suggest that collaborative discourse may allow students to engage in scientific practices that encourage deep processing while engaging in observation, collaborative argumentation, and experimentation.

In this study, two computer simulations were developed to help students understand the underlying scientific phenomena in an aquarium ecosystem. This study explores how students used the simulations to develop collaborative discourse and applied epistemic practices to achieve collaborative scientific conceptual change. Computer simulations play an important role in science education by providing opportunities for learners to infer, reify, and modify their understanding through experimentation (de Jong & van Joolingen, 1998) and stimulate collaborative discussion with highly focused objects for reflection. Papert (1980) argued that computer-supported environments bring in such “mindstorms” in which students can formulate and test alternative hypotheses and reconcile the discrepancy between their ideas and the observations in the micro world. For example, the ThinkerTools Scientific Inquiry and Modeling Project research group found that the computer simulation models help students in developing their metacognitive capabilities, which is essential for intentional conceptual change (White & Frederiksen, 2000).

Collaborative Scientific Conceptual Change Model

To achieve the goal of investigating students’ collaborative conceptual change process, I employed a new theoretical framework to interpret the conceptual change process – the collaborative conceptual change model. This framework echoes with Sinatra’s urges to use multiple theoretical spotlights to understand student conceptual change process. Sinatra (2002) suggested the pursuit of both internal (cognitive and motivational) and external (social and contextual) aspects of conceptual change. Thus, this framework integrates three major perspectives (i.e., cognitive, social, epistemic) to explore the conceptual change process with a particular stress on social and epistemic aspects.

Conceptual change is not easy to achieve because students tend to use their intuition to explain science concepts, which leads to superficial understanding that may be resistant to change despite instruction (Chi, 2005). The distributed nature of cognition suggests that conceptual change requires communication among people (Pea, 1993). Peer discourse may create an awareness of the need for knowledge revision and encourage deep processing, thus is a powerful tool for conceptual change (Roschelle, 1992). In addition, the intersubjective meaning making in peer discourse helps create joint interpretations through phases of negotiation focused on shared information (Suthers, 2006).

However, collaborative learning is not always productive as few students see science as a process of formulating researchable questions, conducting experiments to test ideas, and formulating evidence-based argumentation (Carey & Smith, 1993; Dillenbourg, 1999; Sandoval & Reiser, 2004). Both diSessa (2006) and Linn (2006) question the coherence of the criteria students use for their epistemic practices and advocate epistemic practices entailing systematic observation, argumentation, and experimentation. Students need more opportunities to develop sophisticated epistemic practices such as testing and modifying ideas through experimentation and evidence-based argumentation. Computer tools may support coordinating social interactions. For instance, learning through computer simulations contributes to initiating negotiation to explain observed phenomena and the observation of simulations helps support reflection on the coherence between theories and evidences. The framework of this study argues that on one hand, in the computer-supported collaborative learning context, collaborative discourse makes students' epistemic practices visible and available for comparison. On the other hand, the epistemic practices of science require that students use evidence to support their claims thus producing productive discourse. Such reciprocal relations between collaborative discourse and epistemic practices seem likely to foster collaborative scientific conceptual change.

Research Agenda

I report here on a classroom study using the collaborative scientific conceptual change framework to investigate trajectories of conceptual change in a simulation-supported collaborative learning context. In the study, computer simulations were used as a media to provide opportunities for students to conduct science observation, collaborative argumentation, and experimentation. The computer simulations can mediate students' collaborative discourse and their epistemic practices. First of all, computer tools shape the way students interact with each other, such as how they propose an argumentation or solve a problem. Second, running computer simulations immediately reflects the results of students' epistemic practices of problem solving and such visual feedback help learners develop and adopt sophisticated epistemic practices such as designing experiments, collecting data, coordinating theory and evidence, and testing and modifying hypotheses.

In this dissertation, I first sketch the collaborative scientific conceptual change model – derived from current literature. I then illustrate the embedded relations between collaborative discourse, epistemic practices of science, and conceptual change in the model as well as the trajectories of collaborative scientific conceptual change from a classroom study with students using simulations to study the aquarium ecosystem. Finally I derive some pedagogical implications from the findings of this study.

Statement of Research Questions

The purpose of the study is to test the collaborative scientific conceptual change model by examining the relationships between the patterns of student collaborative discourse, the epistemic practices, and the trajectories of collaborative scientific conceptual change. Specifically, I intend to address the following research questions:

1. What conceptions change occurs as a result of participating in a technology-enhanced curriculum unit for learning about aquarium ecosystems?
2. What collaborative discourse patterns emerge during the collaborative use of computer tools and how are they related to student conceptual change?
3. What epistemic practice patterns emerge during the collaborative use of computer tools and how are they related to student conceptual change?
4. What are the trajectories of collaborative scientific conceptual change?

CHAPTER 2

LITERATURE REVIEW

Review of Conceptual Change Theories

Broadly speaking, conceptual change refers to a process in which concepts acquire new meaning. To clarify the concept of conceptual change, various theorists have offered different views of the process of conceptual change. In this dissertation, I use the definition of conceptual change from science education, which involves students' shift from their initial preconceptions to scientific conceptions (i.e., scientific beliefs, ideas, or way of thinking). In the historical development of conceptual change theories, there are three major factors differentially emphasized in various theories: cognitive, sociocultural, and epistemic. The cognitively focused theories emphasize the importance of cognitive conflict in the process of conceptual change; the socioculturally focused theories stress how social communication and collaborative activities contribute to conceptual change; those focused on epistemic aspects stress the roles that epistemic practices play in conceptual change. In the following sections, I will present a detailed review in these three approaches prior to presenting a general model of conceptual change, the collaborative scientific conceptual change model.

Cognitive Conceptual Change Theories

Conceptual change theories are based on Piaget's concept of knowledge disequilibrium that emphasizes the role of cognitive conflict in learning (Piaget, 1985), as well as Thomas Kuhn's description of scientific revolution (Kuhn, 1971). Piaget (1985) stated that a disequilibrium or cognitive conflict induced students to reflect as they intend to solve the conflict. Kuhn (1971) called such disequilibrium as “a state of crisis” and described scientific revolution as a consistent pattern of shifting from a dominant scientific paradigm to an alternative paradigm with the potential to solve such “crisis”. Posner and colleagues adopted this concept and proposed that knowledge discrepancies play an essential role in fostering conceptual change (Posner et al., 1982). They believe that learning is a rational process “by which people's central, organizing concepts change from one set of concepts to another set, incompatible with the first" (Posner et al., 1982, p. 211). On the practical level, they presented four conditions that foster conceptual change. First, learners should be dissatisfied with their existing conceptions and such dissatisfaction leads to cognitive conflict. Second, the new conception must be understandable to learners so that they can make accommodation in their thinking. Third, the new conception should appear initially plausible so that learners may use that to solve problems or construct explanations of phenomena in current context. Finally, the new conception must be fruitful so that learners can transfer the understanding to other different contexts.

Many other conceptual change theorists followed the view of Posner et al (1982). Some researchers asserted that students’ alternative conceptions in science are very tenacious and that conventional instruction is ineffective in promoting conceptual change. They advocated that one strategy to foster conceptual change was to confront student with discrepant events that contradict their own conceptions (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985). Thagard (1992) proposed that when people encounter something surprising, they naturally generate hypotheses to account for it.

However, other studies indicated that adults, children and even trained scientists failed to make a change in their theories when they face conflicting evidence (Mason, 2003; Kuhn, 1989). Early in 1968, Piaget claimed that people were most likely to ignore knowledge discrepancies. Although Chinn and Brewer (1993) agreed that people should be more likely to change their ideas when in the face of anomalous evidence, in a subsequent study, Chinn and Brewer (2001) reported seven different reactions towards anomalous data, among which most of them failed to change previous theories even in the face of conflicting evidence.

Other theorists such as diSessa (2002) regards conceptual change as the cognitive reorganization of diverse naïve knowledge into complex systems in students minds. diSessa (2006) argues that students hold fragmented pieces of knowledge in their knowledge base which he called as phenomenological primitives (p-prims). According to diSessa, students have “knowledge in pieces” that is loosely connected to generate explanations in particular situations. The property of fragmentation in student knowledge base may induce dissonance between student knowledge and their beliefs. For example, students may possess the knowledge that the Earth revolves around the Sun, but do not believe that. To reach congruence between knowledge and beliefs, justification for knowledge is critically important in students’ epistemic practices of science.

The literature review indicates that knowledge discrepancies or anomalous data are not sufficient to foster conceptual change, which raises the concern that other factors need to be considered to achieve conceptual change, such as the effect of social interactions and epistemic practices. Posner and his colleagues stated their revised conceptual change model and noted that the effects of social or institutional sources including motives and goals need to be considered in conceptual change models (Strike & Posner, 1992). Vosniadou and Ioannides (1998) argue that the conceptual change approaches developed in the 1980s and early 1990s put too much emphasis on sudden insights facilitated by cognitive conflicts. They emphasized the conceptual change as a gradual process with knowledge enrichment and restructuring in situated learning environments and called for increasing the ties between the cognitive developmental and science education perspectives on change. Likewise, Limon (2001) presented similar arguments in favor of the theory of science learning that includes both the individual cognitive development and the situational and cultural factors facilitating it. In the following two sections, I will introduce some conceptual change theories from sociocultural and epistemic perspectives.

Socially-based Conceptual Change Theories

In addition to the cognitive aspect of the process of conceptual change, some researchers noticed the importance of sociocultural factors in student learning. The social artifacts play a role in conceptual change. Social constructivists insist that knowledge develops through social negotiation and through the judgment of the application of the ideas of others. Kublin et al (1998) note that "Vygotsky described learning as being embedded within social events and occurring as a child interacts with people, objects, and events in the environment" (p. 287). Vygotsky (1978) referred to the distance between the abilities displayed independently and with social support as the zone of proximal development (ZPD). This notion reveals a pattern of conceptual change in which a phase of adult, peer or artifacts support precedes a phase of independent conceptual development. More recently, Pintrich and colleagues proposed the definition of intentional conceptual change and stressed that the science content has to be embedded in learning environments that support the acquisition of the rational issues (Pintrich, Marx, & Boyle, 1993). Such support may include the collaborative discourse or use of artifacts.

The sociocultural perspectives are based on the assumption that engaging students in discourse promotes learning (Rogoff, 1990; Vygotsky, 1978). Consistent with this view, a collaborative learning environment is necessary for successful conceptual change instruction. Champagne, Gunstone and Klopfer (1985) proposed a dialogue-based strategy - *ideational confrontation* - specifically designed to alter students' declarative knowledge within a particular domain (e.g., the motion of objects). They suggest that discussion involves considering the views of others and relating a situation under consideration to other real-world phenomena thus is significant in promoting change of views. They also make the point that students must be motivated and that the quality of arguments improved over the course of instruction.

There are several benefits of collaborative discourse in student conceptual change. First, peer interactions may stimulate students to restructure their existing knowledge, which may lead to conceptual change (Smith et al., 1992). In addition, Roschelle (1992) suggested that by asking learners to work together on joint problems, they are faced with challenges of establishing common references, resolving discrepancies in understanding, negotiating issues of individual and collective action, and coming to joint understanding. Roschelle (1992) reported a study in which convergent conceptual change occurred when students collaboratively used a computer-based simulation - the Envisioning Machine (EM) to learn about two physical concepts: velocity and acceleration. He proposed that *convergence* is the crux of collaboration. As misconception research shows, students have strong tendencies for meanings to diverge. Some features of collaborative learning may help students converge of differentiated meanings as they construct meanings for scientific concepts. In the EM study, Roschelle (1992) applied Smith et al's knowledge reconstruction model (Smith, diSessa, & Roschelle, 1993) to explain the process of collaborative conceptual change. Specifically, students restructured their "p-prims", such as commonsense metaphors, to make meaning of a scientific concept. In other words, the students successfully understood a scientific concept without using the standard scientific language. For instance, students referred to the concepts of velocity and acceleration as the "thin" and "thick" arrows and successfully shared the meaning of these concepts by iterative cycles of displaying, confirming, and repairing meanings.

Second, peer interactions in collaborative activities may generate the need for knowledge revision and to consider alternative perspectives from different cultural backgrounds. Duschl and Osborne (2002) suggest opportunities for discussion and argumentation could aid students in considering and evaluating other perspectives and thus helps them revise their original ideas. Scientific argumentation usually involves proposing, supporting, criticizing, evaluating, and refining ideas, some of which may conflict or compete, about a scientific subject, and engages students in using evidence and theory to support or refute ideas or claims (Simon, Erduran, & Obsorne, 2002). Peer collaboration provides opportunities for scientific argumentation to occur. It provides a rich environment for mutual discovery, reciprocal feedback, and frequent sharing of ideas (Damon & Phelps, 1989). Such an environment provides abundant opportunities to arouse dissatisfaction with existing knowledge. Crook (1994) also pointed out three major cognitive benefits of peer collaboration: articulation, conflict, and co-construction.

According to Piagetian perspectives on conceptual change, the discrepant ideas from peers may require students to explain or reflect on and then compare their original ideas with other alternative ones from their peers, thus lead to eventual conceptual change.

Finally, peer interactions may contribute to conceptual change by encouraging deep mental processing. Deep processing includes attending to contradictory information, attempting to make meaning of alternative ideas, looking for evidence to support or dispute a theory, establishing causal relations between the evidence and considering the validity of evidence (Chinn & Brewer, 1993). In collaborative learning, people have the opportunity to convince others by providing evidence to support their own theories and ask for evidence for alternative theories. Such a tendency provides opportunities to encourage deep processing, thus foster conceptual change.

In summary, peer interactions may contribute to conceptual change by creating an awareness of the need for revision of knowledge, initiating knowledge reconstruction, and encouraging deep processing. However, researchers have demonstrated that there was no guarantee that collaborative learning will always be productive and successful (Dillenbourg, 1999; O'Donnell & O'Kelly, 1994). As mentioned before, the development of ZPD involves not only peer support but also support from mediating artifact. In Vygotsky' view (1978), peer interaction, scaffolding, and modeling are important ways to facilitate learning. Thus, the ZPD can also include artifacts such as books, computer tools, and scientific equipments. Barron (2000) found that patterns of interaction marked by individual rather than joint work became problematic when there was a failure to reach common ground when solving a problem. This suggests that it is necessary to find ways to help students achieve common ground when facing novel problems and coordinate efforts in collaborative learning. If a particular instructional tool can increase such coordinated interactions, among groups, this tool may mediate the collaborative activity to foster such successful collaborative conceptual change. The rapid development of computer tools has the potential to offer such affordances. In addition, computer tools provide great opportunities for students to conduct experiments to test their ideas and gather evidence for their claims, and thus develop epistemic practices of science. The notion of ZPD also implies the concept of scaffolding. Wells (1999) referred to scaffolding as "a way of operationalising Vygotsky's concept of working in the ZPD" (p.127). He presented three essential properties involves in educational scaffolding: the dialogic discourse, the rich learning activities (such as epistemic practices of science), and the mediating artifacts.

In summary, despite the essential role of collaborative discourse in prompting student conceptual change, there is no guarantee that collaborative conceptual change will be always successful. Goal-directed learning activities under learners' control are essential for conceptual change, particularly for the intentional conceptual change, to occur. In the following sections, I will elaborate the functions of such learning activities, mediating computer tools, and how they are related to conceptual change.

Epistemic Conceptual Change Theories

Cognitive scientists assert that human cognitive processing has different levels including conscious and unconscious or automatic thoughts or behaviors (Stanovich, 1999). That indicates learners' knowledge construction (i.e., the metacognitive process) could be unconscious or implicit to learners.

Some conceptual change theorists assert the importance of intentional conceptual change, which stresses the importance of intrinsic motivation or self-regulated learning. Scientific knowledge is not simply a body of statements and logical operations. It also includes an understanding of how to do science, knowledge of deep explanatory principles, as well as an integrated knowledge system (Sawyer, 2006). Scientific knowledge is comprised of theory and empirical evidence. It is crucial to interrelate these two pieces together to understand what science is and how it works (Kuhn & Pearsall, 2000). The theory theory views concepts as being related to each other and being part of theories used to explain the world around us (Carey, 1985; Gelman &Wellman, 1991; Gopnik & Meltzoff, 1997; Murphy, 2002). The theory theorists, stress the important roles of explanatory theories in cognition and assume that even young children have their own theories to explain the world. The theory theory thus stressed that to develop scientific understanding of the world, it is extremely important to provide student sufficient opportunities and experiences to develop their theories to explain the scientific phenomena.

The ideal practices of science involve experimentation, trial and error, hypothesis testing, debate and argumentation, which often occur in situated and collaborative contexts. Southerland et al (2001) claimed that knowledge is “understood to be based on an assessment of evidence (in the case of scientific knowledge, the evidence would be judged using scientific epistemic criteria)” (pp. 337-338). Vosniadou (2002) asserts that children begin the knowledge acquisition process by organizing their sensory experiences under the influence of everyday culture and language into narrow, but coherent, explanatory frameworks that may not be the same as currently accepted science.

However, many other researchers argue that students lack coherence in their thinking (diSessa, 2006; Linn, 2006). In other words, students either use different criteria to justify their claims or they lack justification for some claims. However, it is very important to possess coherent criteria for legitimating knowledge claims. The weak foundation for students' knowledge claims may be the reason why students' knowledge construction is frequently at odds with scientifically accepted norms (Osborne & Freyberg, 1985; Palmer, 2001; Trend, 2001).

For students to be effective thinkers, it is important to make their metacognitive experiences visible. Flavell (1979) defined the metacognitive experiences as cognitive events that lead one's own thinking or ongoing cognitive processes. However, students often have very limited metacognitive skills. Schoenfeld (1987) showed that one major reason that students failed to solve problems was due to metacognitive failure rather than lack of basic background knowledge. Training students to conduct epistemic practices may consequently help student become metacognitively aware of their learning process. That is, to help students connect science instruction to their own understanding, their thinking needs to be made visible, explicit and therefore open to epistemic practices that involve reflection and knowledge revision. The computer supported collaborative learning (CSCL) environment can make the individual as well as collaborative thinking visible and explicit for students to state arguments for resolving problems as well as to negotiate and explain conceptual understanding. CSCL environments can help student track their thinking process. The ThinkerTools is a good example to show how computer-based environment may facilitate students in developing their metacognitive capability and how it supports engaging in epistemic practices. White and Frederiksen (2000) report their findings of the instructional trials of the ThinkerTools Inquiry Curriculum in twelve urban classes in grades 7-9. Aiming at facilitating the development of metacognitive knowledge and skills that students need to create and revise their theories, the ThinkerTools incorporates a reflective process in which students evaluate their own and each other's research using a set of criteria that characterize good inquiry, such as reasoning carefully and collaborating well. One of their major findings was that students in the Reflective-Assessment Classes generated higher scoring research reports than those in the Control Classes. In addition, they found that students who showed a clear understanding of the criteria produced higher quality investigations than those who showed less understanding. Thus, there are strong beneficial effects of using computers to introduce a metacognitive language for students' reflective explorations of their work in classroom conversations.

Goldman, Duschl, Ellenbogen, Williams, and Tzou (2003) state that computer-based instruction can make thinking visible. They presented an example electronic environment, the Knowledge Forum (KF), which provided affordances for processes of coordination, construction, and evaluation. Goldman et al (2003) found within the context of SEPIA project, which aimed to promote scientific reasoning and communication, the KF entries were “extremely valuable for taking the pulse of students’ scientific thinking and argumentation approaches” (p. 278). They also suggested that there were some pragmatic constraints since the real application of the KF was somewhat different from what the creators intended. For example, the students only had time to make their own thinking visible but did not examine the entries of other students. Another example CSCL environment is the KIE environment (the Knowledge-Integration Environment, the previous version of WISE). In the KIE, the SenseMaker tool makes it possible to help students see their thinking process as they engaged in argumentation (Bell & Davis, 2000). The SenseMaker helps students figure out the relationships between a numbers of Web resources by asking students to organize the information into categories and use them as evidence to make an argument. The Mildred tool in the KIE software provides conceptual and strategic hints to scaffold students' thinking. All these tools facilitate students in examining their own thinking (Bell & Davis, 2000). Both KF and KIE illustrated that the CSCL environments have the potential to make students' thinking visible and enhance their metacognitive strategies.

CSCL and Conceptual Change

Much research has explored the roles that computers can play in student learning. Kurland & Kurland (1987) summarizes the following five computer functions that support learning:

1. It can allow one to simulate situations that are less likely in the real world;
2. It can maintain traces of student actions that can be used in improving problem-solving strategies;
3. It can reify the process of thinking, not just the product;
4. It can make the invisible visible;
5. It can help create functional learning environment where the student can acquire knowledge while pursuing goals that are meaningful to them.

The first and the fourth functions of computers can be realized through the feature of microscopic representation and simulations. Many scientific phenomena include some invisible microlevel which cannot be observed in real life. However understanding the microlevel phenomena is often essential for learning science. Greenbowe (1994) has suggested the need for computer-mediated instruction for learning chemistry. Most conventional chemistry lectures emphasize the symbolic representation (such as balancing equations) and macroscopic representation (such as changes in state), but leave the microscopic representation unexplored. With the affordance of computer-based technologies, students have opportunities to visualize the invisible phenomena via microscopic representation as well as to represent the dynamic phenomena. Further, simulated environments allow students to get involved with problems through visual media, which provide integrated context and can help students comprehend new ideas more easily. In addition, as to the other three functions, computers can provide realistic complex environments for student inquiry, furnishing information and tools to support investigation, linking classrooms for joint investigations, and presenting data in ways that support scientific thinking and problem-solving skills of the problems that they might encounter in the real life.

Research has shown the particular effectiveness of computers in fostering conceptual change (e.g. Beichner, 1996; McDermott, 1990; White, & Horwitz, 1988; Zietsman, & Hewson, 1986). McDermott (1990) found that the interactive computer application *Graphs and Tracks* helps students make connections between motions and their graphical representations, using the example of balls rolling on tracks with varied slopes. Consistently, Beichner (1996) proposed that technology-based instructional approaches, such as microcomputer-based laboratories and digital video analysis of experimental data, have great potential to contribute to the development of deeper understanding and conceptual change in science, because these technologies allow examination of interactions and collisions that is more direct and obvious than with traditional laboratory methods. In one study (Beichner, 1996), introductory physics students in a variety of instructional settings used a video analysis software package - the *VideoGraph,* which allowed students to compare videos directly with synchronized, animated graphs and to measure slopes and areas on the graphs. It was expected that this would help them bridge the gap between the concrete visual display of a motion event and its abstract graphical representation. The outcome of the post-instruction assessment of students' ability to interpret kinematics graphs clearly establishes that students using this software performed better than those taught via traditional instruction.

One of the most important steps in the process of conceptual change is to discover cognitive conflicts and resolve the conflicts. Unfortunately, it is hard for students to realize the discrepancy between their own ideas and the subject knowledge, because students are inclined to adopt existing explanatory concepts and theories without thinking and reflection on them. Papert (1980) argued that computer-supported environments bring in such "mindstorms" in which students can formulate and test alternative hypotheses and reconcile the discrepancy between their ideas and the observations in a microworld. That is, the computers help students to discover the discrepancy by providing contexts for students to test out their original hypotheses and showing the consequences of their hypotheses. Zietsman and Hewson (1986) conducted a study to investigate the effects of instruction using computer simulations along with conceptual change strategies by comparing student responses to questions about actual balls moving on rails to animations of the same situations. Students who had been identified as holding a misconception about velocity participated in a computer remedial program, designed to address specific misconception with examples and experiments when the student's current conception would not explain the observations. The results showed that students in the experimental group made fewer mistakes on the diagnosing test and therefore experienced greater conceptual change. This study showed that the computer simulation may highlight the misconceptions that students hold and help themselves to realize these misconceptions by experiments and thus make appropriate accommodation to improve their conceptual understanding.

White and her colleagues (White, 1993; White & Horwitz, 1988; White & Frederiksen, 2000) developed a set of simulations called Thinker Tools. Thinker Tools operated in a manner consistent with the Newton's first law. After using the ThinkerTools, sixth grades students who experienced ThinkerTools outperformed high school physics students who had just completed a unit on mechanics on a test of conceptual understanding of the first law. Consistent with Zietsman and Hewson (1986), White and Horwitz (1988) found that the use of computer tools could help users in becoming aware of the inaccuracy and inconsistency of their own conceptions, thus leading to discrepancies between the observed conceptions and existing personal concepts. These findings indicate that computers have the potential to help students see the discrepancies in their naive ideas and scaffold conceptual advancement.

In addition, research found that the computer-supported environment might help students in developing their metacognitive capabilities, the importance of which is stressed by the intentional conceptual change researchers. The ThinkerTools Inquiry Project research group found that ThinkerTools helped students' capabilities of planning in their inquiry (White, 1993). The ThinkerTools curriculum focuses on facilitating the development of metacognitive knowledge and skills needed to create and revise their theories through an instructional inquiry cycle consisting of motivation phase, model evaluation phase, formalization phase, and transfer phase. Middle school students used the software to develop understanding of physical theories. The purpose of using the software was to let the children discover and construct these theories by doing experiments, creating models, evaluating models, and revising the theories. Once they finally selected the best theories and causal models, they applied them to different real-world situations by predicting and explaining what would happen. The results show that the intermediate models in ThinkerTools software help make the subject of physics understandable to most students thus lead to successful but gradual conceptual change.

In summary, empirical evidence demonstrates that computer-supported learning environment may promote the process of conceptual change in two ways. First, they have the potential to help students realize the discrepancies in their original ideas and notice the existence of alternative ideas. Second, they may provide affordances for developing students' metacognitive skills, such as planning, self-regulating, and monitoring.

Collaborative Scientific Conceptual Change

The literature suggests the need for an integrated model – the collaborative scientific conceptual change model, which involves three major elements within conceptual change: cognitive conflict, collaborative discourse, and epistemic practices of science (see figure 1). Collaborative scientific conceptual change occurs when learners co-construct new knowledge and make a shift from their previous ways of thinking towards the scientific ways of thinking that scientists are inclined to use to explain phenomena. This definition stresses two factors in student conceptual change: the effect of social interactions and the shift towards epistemic practices of science. The reciprocally facilitating relations between collaborative discourse and epistemic practices combine the two perspectives together. In collaborative discourse, students realize the need for knowledge revision. Thus knowledge discrepancies are discovered in conversations, which stimulates knowledge reconstruction to solve the discrepancy. More importantly, collaborative discourse encourages deep processing for students. The sociocultural view illuminates that the collaborative discourse may lead to a shared ZPD among students that allows them to engage in practices that are not supported by individual learning, such as scientific observation, collaborative argumentation, and experimentation. Furthermore, the collaborative discourse may also make epistemic practices explicit, thus make metacognitive thinking visible and comparable. For example, during the epistemic practice of coordinating theory and evidence, the underlying criteria students use to justify their claims is exposed to other students who can monitor the coherence of criteria in the discourse.

On the other hand, the use of various artifacts (e.g., learning resources and CSCL environments) affords opportunities for students to conduct science observation, collaborative argumentation, and experimentation. Such epistemic practices provide evidence base of coherence for student collaborative discourse. Activity Theory puts emphasis on social factors and on tool mediation (Engestrom, 1999). It explains why the use of tools mediation is an accumulation and transmission of social knowledge. In the case of CSCL learning environment, first of all, computer tools shape the way students interact with each other, such as how they propose an argument or solve a problem.

Second, computer tools reflect the experiences of peers who have tried to solve similar problems and to modify their ways of using tools to make learning more efficient. So, the use of computer tools is a means for the accumulation and transmission of social knowledge. In this way, the epistemic practices shape collaborative discourse.

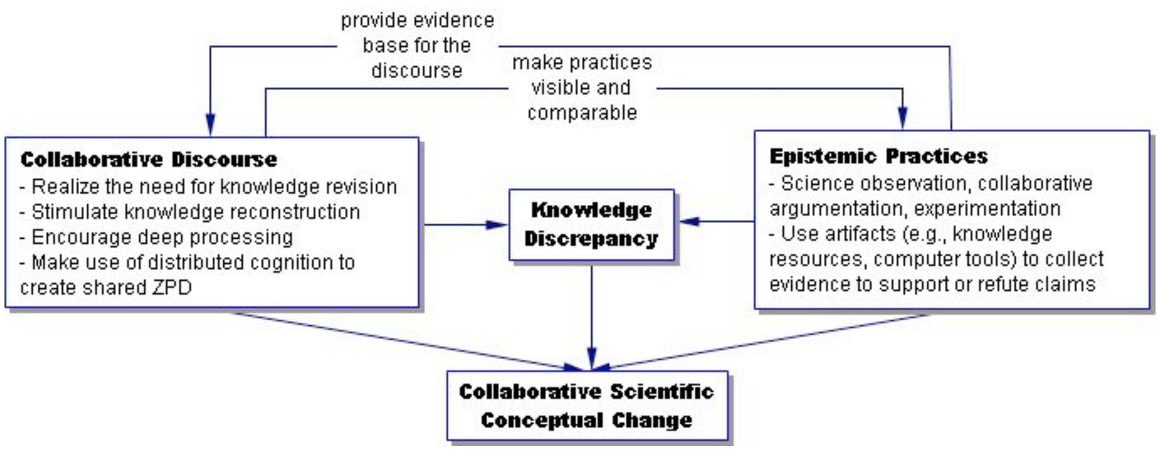

Figure 1. Collaborative Scientific Conceptual Change Model

Learning about the Aquaria Ecosystem

Learning about Complex Systems

Numerous features of complex systems make them hard to understand. Understanding complex systems involves thinking about multiple interdependent levels, non-linear causality and emergence (Jacobson & Wilensky, 2006). One of the cognitive barriers to understanding such systems is that these levels are dynamically linked. Studies of complex systems demonstrate that student understanding focuses on the perceptually available structures (Hmelo, Holton, & Kolodner, 2000; Hmelo-Silver, Marathe, & Liu, 2004; Hmelo-Silver & Pfeffer, 2004; Mintzes, Trowbridge, Arnaudin, & Wandersee, 1991; Wood-Robinson, 1995). In other words, students tend to ignore invisible and dynamic phenomena, which causes substantial barriers to understanding the whole system (Feltovich, Coulsen, Spiro, & Dawson-Saunders, 1992). In complex systems domains such as the human respiratory system and aquarium systems, expert-novice comparison studies demonstrate that novices tend to think about isolated structures whereas experts integrate behavioral and functional perspectives (Hmelo-Silver et al., 2004; Hmelo-Silver & Pfeffer, 2004). Moreover, making connections among different levels (e.g., the macro and micro levels) of a complex system places a heavy load on working memory. This is particularly true in learning about life science such as ecosystems because many ecosystems are characterized by complex and nonlinear causality as well as interwoven relationships between macro- and micro-level phenomena. Unfortunately, such difficulties in learning about complex systems are not sufficiently addressed in traditional textbooks.

A recent study by Project 2061 developed a curriculum-materials analysis process to determine the degree to which science and mathematics textbooks are aligned with the National Science Education Standards established by the National Research Council (NRC, 1996), Benchmarks (AAAS, 1993) and other standards. This project group found serious weaknesses in the science textbooks that were the most widely used ones in American schools. Some of their major findings (AAAS, 2000) illustrated that most textbooks ignore or obscure many of the most important concepts by focusing instead on technical terms and trivial details that are easy to test. In addition, students are given little help in interpreting the results of activities in terms of the science concepts to be learned. The important supporting ideas about the nature of scientific theories and how evidence is gathered and interpreted that is typically omitted in most of the textbooks. Acknowledging the serious weaknesses of textbooks, Ulerick (2000) suggests some alternative approach to learning and instruction. She suggested several powerful strategies to improve student understanding, including: (a) obtaining background or explanatory information for targeted projects; (b) obtaining data, or (c) challenging their own ideas with new viewpoints.

The Domain of Study

The aquarium ecosystem, an example of a complex system, was the science domain for this study. It includes both macro and micro levels components. Some major macro level components include fish, food, plants, filters, air pump, light; micro level components include bacteria and other micro-organisms, the chemicals involved in the nitrification process (ammonia, nitrite, nitrate), oxygen, and carbon dioxide. It is difficult for students to develop a systematic understanding of such a complex system because the macro and micro level components are dynamically interrelated with each other to maintain a balance in the system. For instance, the fish produce waste composed of toxic chemical, ammonia. The gravel provides a place for the colonies of beneficial bacteria to survive and reproduce, ensuring that the aquarium remains healthy by converting the ammonia into less harmful chemicals, such as nitrite and nitrate. As a closed system, some designed components are needed to maintain the equilibrium in aquarium, such as the filter, heater, and light. Part of the filter is the biological filter, which is composed of bacteria that convert ammonia to less toxic chemicals. The primary source of ammonia is from the fish waste. Bacteria in the water first convert the ammonia into less toxic nitrite and finally non-toxic nitrate, some of which can be used by plants as fertilizers. This process of changing harmful ammonia into less toxic nitrate is called the *Nitrogen Cycle* in an aquarium. Figure 2 illustrates the relationships involved in the cycle.

The Nitrogen cycle is an example biogeochemical cycle. The Nitrogen cycle is important to maintain a healthy aquarium system. In the middle school science learning and teaching standards, the nitrogen cycle has been included in many domains, such as biology, earth science, and chemistry. Learning about the nitrogen cycle in the aquaria system, an artificial ecosystem, represents a model complex system learning process, which requires understanding of the interrelations between macro- and microscopic scale phenomena.

Consistent with Ulerick's ideas (2000), for the purpose of facilitating students understanding the aquarium ecosystem, we designed a computer-supported learning environment providing such affordances as providing background information, tools to observe and gather data to test ideas, and collaborative opportunities to challenge students' ideas with new viewpoints. In the next section, I will introduce this designed environment.

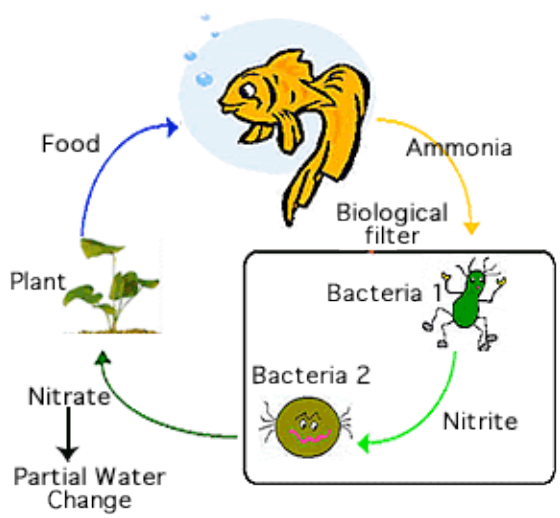

Figure 2. The Nitrogen Cycle in the Aquarium.

CHAPTER 3

METHODOLOGY

Participants

The participants in this study were 145 middle school students from two public schools who volunteered to participate in this study. Seventy were seventh graders taught by Ms. W. Seventy five were eighth graders taught by Mr. K. They were randomly assigned into groups by the teachers and twenty focal groups' interactions were video and audiotaped. The study was conducted in seventh and eighth grades as part of students' science instruction.

Materials

The RepTools toolkits[1] includes a hypermedia and two NetLogo (Wilensky & Reisman, 2006) computer simulation models. The hypermedia introduces the aquarium system with a focus on the functional aspects but provides linkages between the structural, behavioral and functional levels of aquariums. Therefore, we designed and developed the hypermedia to meet the following requirements: (a) providing connections between knowledge addressing "what", "how", and "why", (b) highlighting a meaningful and function-centered text structure, (c) providing a different levels of detail (e.g. applicable conditions) surrounding a few central functional ideas in a hierarchical way. By exploring this hypermedia, students can construct a basic understanding of the system to prepare them for their inquiry activities with the simulations. The hypermedia can also be

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[1] This project was funded by an NSF CAREER grant # 0133533 to Dr. Cindy E. Hmelo-Silver. The RepTools toolkit design is part of the project. I am one of the principal designers.

available as a reference to help students interpret the simulations. Figure 3 shows the opening screen of the hypermedia. The hypermedia introduces students to this system with two big functional and behavioral questions on the opening screen: “Why is it necessary to maintain a healthy aquarium?” and “Why do fish and other living things have different roles in the aquarium?” By clicking on these questions, the students can go to information about the functional aspects of the system, then to the behavioral aspects and finally to the structural knowledge.

To facilitate students’ understanding of the system, we programmed two simulation models using NetLogo (Wilensky & Reisman, 2006). Students could run and observe the simulations, generate and test hypotheses, and modify ideas based on observed results. The two simulations (the fish spawn model and the nitrification process model) present the system knowledge at different scales. The fish spawn model is a macro level simulation, simulating how fish spawn in a natural environment. We used pink and blue fish-shaped representations to embody the fish gender and yellow dots to represent the fish food. The purpose of this simulation model is to help students learn about the relationships among different aspects of an aquarium ecosystem, such as the amount of food, initial gender ratio, filtration, water quality, reproduction, and fish population. The nitrification process model presents a micro level simulation of how chemicals reach a balance to maintain a healthy aquarium. We used red, white, and yellow dots to represent the chemicals (ammonia, nitrite, nitrate respectively) in the water and blue and purple patches as two different types of bacteria. This simulation allows students to examine the bacterial-chemical interactions that are critical for maintaining a healthy aquarium and to reflect how such interactions affect the water quality represented in the macro level simulation. The symbolic representations in both simulation models initiated students' collaborative discussion by providing shared references that were initially puzzling. Both simulations allow students to adjust the values of variables and observe the results. The manipulable representations guided students to useful learning interactions as they designed experiments to test ideas. In both NetLogo simulations, students can adjust the values of variables such as fish, plants, and food and observe the results of the adjustment, by sliders. Figures 4 and 5 show example screens from the two models. Counters and graphs provide alternative representations for students to examine the results of their inquiry. Students can observe the simulations, generate hypotheses, test them by running the simulation and modify their ideas based on observed results.

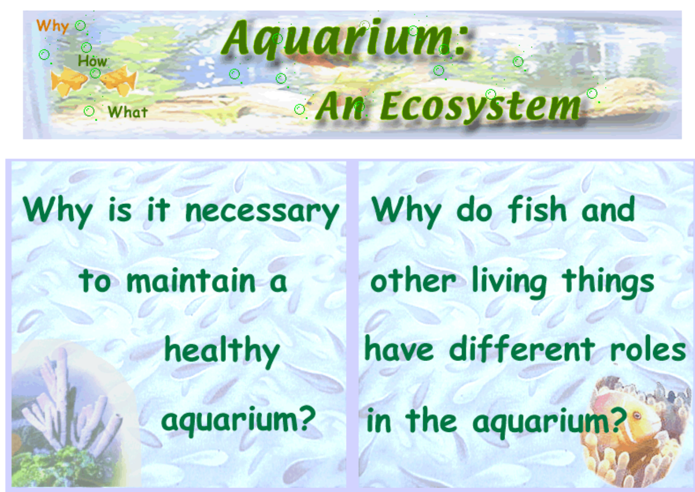

Figure 3. Opening screen of aquarium hypermedia.

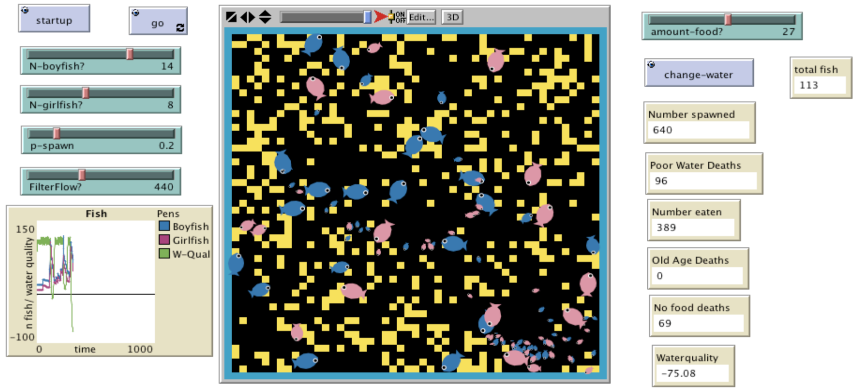

Figure 4. Screenshot of the Fish Spawn Model.

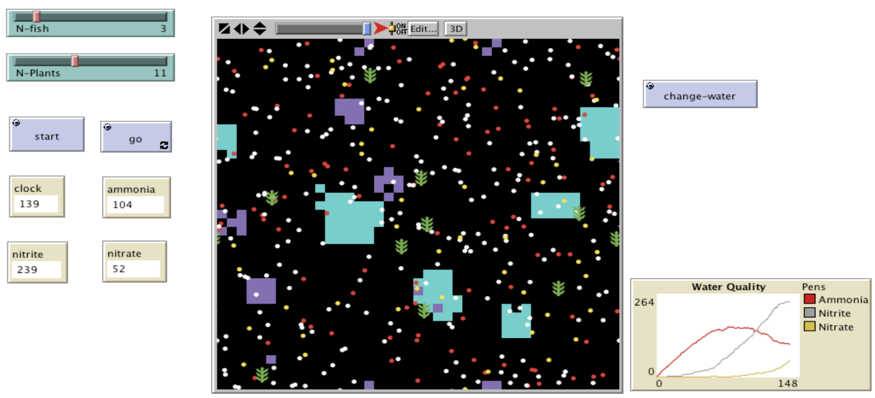

Figure 5. Screenshot of the Nitrogen Cycle Model.

To assess student learning achievement after the intervention of RepTools toolkit, we asked the students to take pre- and posttests. The pre-/posttests asked the students to draw all the parts of an aquarium and label the diagram, followed with questions and problems to elicit their knowledge about the aquarium system (see appendix A). The questions included a list of items and asked how these related to an aquarium (e.g., filter, heater, algae, etc.), several open-ended questions, and problems to solve in which students were asked what would happen if the system was perturbed. For example, “What would happen if you suddenly added 10 new fish to the 12 guppies already in a 20-gallon tank? How would that affect the systems' ability to remove ammonia from the tank?"

Procedures

The goal of the study was to support middle school science curriculum instruction and to promote deep scientific understanding of the aquarium ecosystem through the use of computer simulations. We collaborated with two public middle school science teachers to develop specific curriculum units. Prior to enacting instruction, the teachers participated in a two-week professional development on the content and tools.

In both classroom settings, teachers were asked to facilitate students on using computer simulations to learn about the aquarium ecosystem. Before the classroom study, both classrooms had a physical aquarium model installed and maintained for about two months. All learning activities were completed in small groups, the size of which varied from 2 to 6 students.

Classroom Contexts

The two teachers used different teaching approaches due to existing differences in curriculum focus of the school districts and their previous teaching experiences. Ms. W designed worksheets (see Appendix B and C for the worksheets for two simulation models) with open-ended questions for groups while they explored the computer tools. All the groups were required to write down answers to the questions on the worksheets during exploring the simulation models. Additionally, she expected homogeneous progress for the whole class and provided direct instructions to frame group activities.

Mr. K was more inquiry-oriented and tended to scaffold groups' progress with explanatory questions and prompted students to explain their observations. Instead of giving designed worksheets to the students, he required the students to keep notes of discovered patterns and numerical data when a certain pattern occurred in the simulation models (e.g., the number of fish, the rate of filtration, the number of different types of dots). At the end of group exploration, every group was required to write a reflection journal to build a model to summarize and explain observed phenomena during their exploration both simulation models. In addition, Mr. K encouraged heterogeneous progress among the groups and facilitated student learning by using open-ended questioning.

Both teachers used the unit for approximately two school weeks and succeeded in getting students engaged in most of the learning events. In both classrooms, before using the computer simulations, both teachers started with a class discussion on the aquarium ecosystem to activate students' prior knowledge and make connections to the physical fish tank in the classrooms. Then the teachers introduced the hypermedia. The students explored the hypermedia software in groups followed by other activities such as class discussions and construction of concept maps that connected parts of the system to their function. Then the teachers conducted a demo class to introduce students to how to use the NetLogo simulations by demonstrating one sample model unrelated to the aquarium system. The students then collaboratively explored the fish spawn simulation and the nitrification process simulation. Students took individual pre and posttests. Twenty focal groups' collaborative activities were video and audio taped. This paper reports the results the learning gains of all the students in both classrooms and explores the learning process of the focal groups' exploration of the computer simulations (a four-day intervention of pure group exploration and discussion).

Data Coding

Data Sources

There were two major data sources for the proposed study: pre/post-tests and the video/audio data of students' collaborative exploration of the NetLogo models. From the pretests, I identified prior conceptions that students had in the domain of aquarium system. By comparing the posttests with the pretests, I identified the newly constructed concepts as well as those that changed during and after all the learning interventions. The video and audio data will be used to keep track of the path of students' concept understanding and complex system understanding as well, including the interactions between groups, within groups, between students and teachers, between students and experimenters. The coding and analyses of the pre- and posttests addressed the first research question, which investigates the learning outcomes. The coding and analyses of the video/audio data will address the remaining three research questions, which investigate the learning process.

The pre- and posttest data. An SBF-based coding scheme (Hmelo et al., 2004; Hmelo-Silver & Pfeffer, 2004) was applied to code the conceptual understanding in the pre- and posttests of the students in the focal groups. The tendency of learners to focus on observable structures and simple explanations suggests that the SBF representation may provide a deep principle that is useful for thinking and learning about complex systems. SBF theory describes a complex system's multiple interrelated levels, and its dynamic nature. This representation was developed in artificial intelligence to support reasoning about designed systems (Goel et al., 1996) but only recently has been applied to natural systems (Hmelo et al., 2000; Hmelo-Silver & Pfeffer, 2004; Hmelo-Silver, Marathe, & Liu, 2006; Liu & Hmelo-Silver, 2006; Liu, Hmelo-Silver, & Marathe, 2005).

The SBF analysis used a fine-grained coding to assess the students understanding. In the first column of the coding sheet, an exhaustive list of all the structures of the aquarium ecosystem system, such as fish, plants, water, filter, light, algae, gravel, food, air pump, bacteria, heater, rock, snail, decoration. In the first row, all the coding variables were listed, such as structures, behaviors and functions. For each component, any presence of the structural knowledge, such as fish, plants, filter, was coded as structure. The presence of the mechanisms of the components was coded as behavior. For instance, the behavior of the plants is to absorb the carbon dioxide in the fish tank and produce oxygen through photosynthesis. The presence of the role of a component in the system was coded as function. For example, the function of the filter is to clean and circulate water. All protocols were coded blind to condition by one rater. To check reliability, another independent rater coded 20% of the data and the overall agreement was greater than 90%. For example, the mention of the filter was coded as a structure, the mechanisms of removing fish waste as a behavior, and the need to clean water or maintaining equilibrium in the system as a function. A target S, B, or F could only be coded once.

The video/audio data. The video and audiotapes of the groups' discourse throughout their exploration of the computer simulations were transcribed verbatim. The discourse was segmented by turns. Three sets of codes were developed and applied to investigate students' collaborative learning through different lenses. Both the collaborative discourse coding and the epistemic practice coding were conducted at the level of conversational turns. A conceptual change code was given when a new level of understanding occurred. Both the transcripts and the codes were imported into the Multiple Episode Protocol Analysis (MEPA) software (Erkens, 2005), for frequency calculation, pattern identifications by inductive possibility calculation, and sequential data analysis. Quantitative analyses were used to look at students' learning outcomes and how group and teacher factors affected students' individual learning. In addition, case studies were developed to investigate how students collaboratively construct knowledge through the use of computer tools. To make both the collaborative discourse coding and the epistemic practice coding exhaustive, a miscellaneous code was added in both coding schemes, a code for turns that could not fall into all other coding categories.

The *collaborative discourse* coding scheme was designed to uncover cognitive and metacognitive processes underlying the groups' discourse as well as the facilitators' roles (see definitions and examples in Table 1). There are three major subcategories in the coding scheme: students' cognitive processing, students' metacognitive processing, and teacher's facilitating. All the codes under the first two subcategories were used for students' conversational turns only, and those under the third subcategory were used for teacher's conversational turns. These coding categories are indicative of different aspects of students' cognitive and metacognitive engagement or teacher's scaffolding strategies. For example, different types of questioning (i.e., fact, explanation, confirmation questions) initiate different level of elaboration and thinking. Though sharing knowledge, learners exchange ideas about how they make meaning of the knowledge. The dis/agreement among group members presents the extent of convergence in the collaborative learning. Paraphrasing, warranting claims, describing observation, retrieving prior knowledge indicate the trajectories of students' inquiry. Identifying cognitive conflict explicitly present the knowledge disequilibrium during the collaborative knowledge co-construction. The planning, monitoring, reviewing and evaluating are the essential metacognitive strategies that learners apply to guide their thinking and inquiry process. Since the focus of the study is on students' interaction, the facilitators' interactions are coded into four rough categories to indicate the teachers' facilitation styles. Particularly, the educational and performance statements indicate whether the focus of facilitation is on understanding or on tasks. The open and closed questioning indicate how the facilitators scaffold understanding.

The second coding scheme was developed to capture the characteristics of *epistemic practices* (i.e., the practices embodying ways of scientific thinking and how learners work on knowledge construction task, see in Duschl & Osborne, 2002) to build understanding (see definitions and examples in Table 2). The coding categories present a set of discursive practices for generating and evaluating knowledge. The basic knowledge construction is a low level practice of superficial meaning making without deep mental processing. Exchanging knowledge and giving feedback are common practices during collaborative learning to explicitly articulate knowledge and respond to each other. The coding list also includes other practices common to science inquiry, including predicting, designing experiment, coordinating theory-evidence, modifying knowledge, checking knowledge validity. These categories are essential indicators to show how students construct theories to interpret the computer simulations. Scientists often go through cycles of such practices to modify existing knowledge and construct sophisticated theories and develop epistemological understanding. It is necessary to clarify that the coding for modifying knowledge is not simply changing ideas. Rather it was coded as modifying knowledge only when the learner was metacognitively aware of the reasons for such a change. The scaffolding category is used for facilitators' supporting practice only.

The third coding scheme identified hierarchical levels of *conceptual understanding* (Murphy, 2007). At the lowest level, the recognizing level (level 1), students engage in a low level of cognitive processing, such as proposing ungrounded hypotheses of what symbols (e.g., the dots and patches) represent in the simulation models or identifying the patterns of observed phenomena. At the explanatory level (level 2), students either build upon their initial hypotheses with elaborated explanations or propose a grounded hypothesis that includes causal relationships between representations. At the critiquing level (level 3), students criticize the stated understanding by checking knowledge validity and identifying the gap between the evidence and previous hypotheses. Finally, the examined level (level 4) represents the greatest depth of conceptual understanding. At this level, students have checked the validity of their understanding, which they believe is supported by the collected evidence.

The validity of the coding schemes was achieved by reference to related literature and consultation with experts. Reliability was achieved by training an independent coder who then coded 20% of the groups' transcripts. The interrater reliability was assessed by calculating the percentage of interrater agreement and the Cohen's kappa tests. The interrater agreement for the collaborative discourse coding is 91.76% and the Cohen's kappa is 0.888; the interrater agreement for the epistemic practice coding is 93.33% and the Cohen's kappa is 0.884; the interrater agreement for the conceptual understanding coding is 87.19% and the Cohen's kappa is 0.931.

Table 1. Definitions for collaborative coding categories.

Categories	Definitions	Examples
Cognitive Process		
Fact Question	Questions asked with a purpose to obtain factual information	“What is the yellow stuff?”
Explanation Question	Questions asked with a purpose to obtain cause-effect information	“Why is water qualify dropping?”
Confirm Question	Questions asked to make sure one gets the shared information	“The males couldn't wait to make more fish so they what?”
Directing Statement	Demanding statement for an ongoing activities	“Change the water now.”
Agree	Explicit express of acceptance of other’s ideas	“Okay I guess that makes clear sense.”
Disagree	Expressing express of rejection of other’s ideas	“No. This is not true.”
Share Knowledge	Share information with other members in the group	“I have fish, plants, bacteria1, bacteria2, ammonia, nitrite and nitrate.”
Describe Observation	Descriptions on what is observed in the simulations	“Now there are no more male fish”
Retrieve Prior Knowledge	Making connections to one’s previously perceived knowledge or experiences	“We know that there is bacteria inside the water that eats the bad bacteria.”
Generate Theory	Statement of a hypothetical proposal	“When there were more female fish they ate all the smaller fish and then died.”
Paraphrase	Rewording other’s statements	“Okay so when there were more female fish they ate the smaller fish and died of old age.”
Warranting claim	Statements to provide ground for an idea	“Well we are looking at the chart and it tells how ammonia, the bacteria turns it into nitrate. Doesn't it kind of prove that the stuff in the back is bacteria then”

Identify Cognitive Conflict	Realizing the discrepancies in one's or the group's reasoning	"Because the model we have is that when there are more female fish they eat the smaller fish and then they died of old age. But then they are eating the smaller fish and none of them are dying of old age."
Off-topic Talking	Statement unrelated to the learning target	"Can I borrow your pen?"
Metacognitive Process		
Plan	Defining the learning goals	"Okay we have to figure out what they do."
Monitor	Reflecting on the learning process to keep track of the conceptual understanding	"We haven't explain how they keep a balance?"
Review	Looking back on the strategies (e.g., designing experiments, running simulations) that lead to knowledge construction	"Well we tried to take away the plants … and then nothing even happened"
Evaluate	Judging the effectiveness of learning strategies	"Using one fish for each gender helped to find out which gender lives longer."
Facilitators' Roles		
Educational Statement	Statements related to the learning content and strategies	"You need to move on to the next question."
Performance Statement	Statements related to class management and students' performance	"Try to look at the hypermedia. Maybe you will get some information there."
Open Question	Questions seeking an elaborated answer or explanation	"How do you know the water quality has decreased?"
Closed Questions	Questions seeking a short and factual answer	"Are all of those bad for water quality?"

Table 2. Definitions for epistemic practice coding categories.

Categories	Definitions	Examples
Basic Knowledge Construction	Superficial meaning making practice without reasoning or supporting evidence	“What is the yellow? Yeah, I think is food or is that like dirt?”
Observe	Practices of observing phenomena on the computer screen	“Wow! Look it, it went down real quick.”
Predict	Practices aiming to propose predicting result of a simulation	“And if you increase it to 2000 they'll die more quicker.”
Design Experiment	Designing a simulating experiment to test hypotheses	“How about we if put this, and this all the way down to zero? And put this thing on the top?”
Check Knowledge Validity	Examine the consistency or accountability of constructed knowledge by taking several experimental trials.	“No, see this number is like the same, whatever this corresponds to this. It's still 8. Ammonia and saturated in nitrite. But 82 and 75…it adds up to the same number.”
Coordinate Theory-Evidence	Practices entailing using theories to explain data and using data to evaluate theories	“So the plants absorb nitrite because the yellow disappeared. Nitrite, which….comes from nitrate. Nitrate with an A, nitrate comes from nitrite, nitrite comes from ammonia, from the bacteria, the white went in and went through the patch.”
Modify Knowledge	Making a change in previously constructed knowledge with metacognitive awareness of the reasons for the change	“No, the patch is not fish. It is bacteria.”
Exchange Knowledge	Explicit articulation of one’s knowledge to others.	“So you are saying fish excrete ammonia to become nitrite.”
Give Feedback	Providing evaluative responses to other’s statements or actions	“Yes, you are right. The red dots disappeared.”
Scaffold	Applying purposeful strategies to support other’s understanding (subjected to teacher’s conversational turns only)	“So what does that explain about different kinds of models?”

Data Analysis Framework

The evolution of the analysis framework was a consequence of the overarching goal of this study – to investigate how students use computer tools to achieve conceptual change via collaborative interactions and epistemic practices. A mixed quantitative and qualitative analysis method was applied to investigate both students' conceptual understanding achievement (conceptual change) and their group interaction that lead to such achievement (trajectories of conceptual change). The understanding of students' conceptual understanding achievements was achieved through analyzing the differences in their pre- and posttests, which was reported in one of our earlier papers (Hmelo-Silver et al., 2007). The unit of analysis here was the individual student. In addition, to reflect the constructivist research paradigm, the co-constructed conceptual understanding displayed in students' collaborative discourse were considered as students' collaborative learning achievements. The unit of analysis was the group of students. As introduced in previous section, students' conceptual understanding level for various concepts was coded in their group protocol.

The understanding of the trajectories of students' conceptual understanding was achieved through analyzing their verbal data during their collaborative activities using the two simulation models. The unit of analysis was the group of students. Through the collaborative coding and the epistemic practice coding, the raw data was synthesized with codes as evidence of their cognitive, metacognitive, and epistemic thinking. These codes were analyzed through sequential analysis to identify sequential patterns embedded in students' collaborative discourse and epistemic practices. The sequential analysis was used to study the relations between discourse turns and to determine which interaction support student conceptual understanding. Furthermore, the qualitative case studies were also conducted to look into students' learning process.

Finally, to achieve combined understanding of students' conceptual understanding achievements and their collaborative learning process, multilevel analysis was conducted to identify what features in students' collaborative discourse as well as their epistemic practices made significant contribution to their conceptual learning achievements. This analysis combined two kinds of unit of analysis: the individual students and the groups. The following sections elaborated in details of how different analyses were conducted in the study.

Pre/Posttest

To examine learning outcomes, the pre and posttests were coded using an SBF coding scheme (see Hmelo et al, 2000 for details). All the codes for each component in the system were counted. In this study, a mixed 2x20x2x3 ANOVA was conducted with teacher and group as the between-subject factors and time (pre and post) and SBF level as within subject factors to examine whether groups affect students' learning gains. The teacher variables were used based on the assumption that the teachers may affect groups' interaction thus affect students' learning gains.

Coded Transcripts of Collaborative Conversations

As described in the data coding section, all the groups' collaborative conversations were coded from three perspectives: collaborative discourse, epistemic practices, and conceptual understanding level. As for the first two coding perspectives, the transcripts were subjected to a fine-grained analysis of collaborative activities, coded on a turn-by-turn basis. The last coding perspective was coded only when a new level of understanding occurred. The total conversational turns for each coding category as well as the total conversational turns for each group were counted. The percentage of each coding category's frequencies was calculated by using the total turns for that particular category divided by the total conversational turns. To compare whether there was difference in groups' mean scores in the posttest, one-way ANOVA analysis was conducted to compare the group mean SBF scores in the posttests. Likewise, the percentage for each category in the collaborative discourse and the epistemic practice coding schemes were calculated to explore the effect of different teachers.

The one-way ANOVA analysis is not sufficient to tackle the relationship between students collaborative activities and their learning outcomes, because it returns a significant result when it finds a difference between *any* of the independent variable means and the aggregate mean and cannot infer any causal relations. To explore how the groups' activity changes as students converge on shared conceptual understanding, a more advanced statistical method – the Multilevel Data Analysis, was applied.

Multilevel Analysis

To investigate how group interactions and teachers' facilitation influence individual students' learning gains, multilevel analysis method is used to analyze the hierarchically nested data. Multilevel analysis (MLA) is a methodology for the analysis of data with complex patterns of variability, with a focus on nested sources of variability (Snijders & Bosker, 1999). The MLA method deals with the question of how to appropriately grasp and disentangle the effects and dependencies interplaying across the multiple levels (Strijbos & Fischer, 2007) by allowing variance in outcome variables to be analyzed at multiple hierarchical levels.

In the social learning context, particularly in the CSCL learning environment, many factors in the social contexts (e.g., group interaction and teachers' facilitation in this research) may have great influence on individual students' learning performance. It is clear that students' learning activities are non-independent. For example, students taught by one teacher tend to be more similar with respect to their performance. That is, each student provides less information than would have been the case if they were taught by different teachers. Likewise, the students in one group tend to be similar with respect to their performance. That is, students in groups and classes provide information not only regarding individual learning but also regarding the effectiveness of group learning and teachers' facilitation. Many researchers often resort to focusing separately on the individual level and/or on the group (or teacher) level. Focusing on the individual level ignores the variability due to groups and tends to produce false positive results. Collapsing data over individuals to focus on groups ignores a lot of information and provides low power for the number of observations. To explore the relations between group factors as well as between individual factors, some researchers turn to simple linear regression or multiple linear regression. This is also inappropriate because all effects are modeled to occur only at a single level.

To address the issue of non-independence and the power issue, MLA was used to examine the nested effects of different levels of factors. MLA not only produces power and correct p values at all levels, but it also makes it possible to answer simultaneously questions at each level, for instance between groups as well as between individuals, using group-level and individual-level predictors. To put in a simple way, MLA is a more advanced form of simple linear regression or multiple linear regression (Snijders & Bosker, 1999; Singer, 1992). Specifically, the MLA Models can be expressed by writing a single equation that specifies the multiple sources of variation, which is called mixed and multilevel modeling. In this way, MLA is very beneficial in solving the unit of analysis problem that is essentially challenging in social science research.

Mixed model in which the levels are combined into two equations, one for *fixed effects* and the other for *random effects*. The fixed effect is caused by the fixed variables, which are observable and assumed to be measured without error. In this study, the fixed effects include the effects of the variables at different levels (e.g., the group and teacher levels) that this research was interested in, including the group discourse variables, the epistemic practice variables, and the teacher facilitating variables. The random effect is normally caused by the random sampling of a larger population. In this study, there are three random effects at the teacher, group, and individual levels.

In this research, there are three levels of hierarchically nested data: individual student (Level 1), group interaction (Level 2), and teachers' facilitation (Level 3). There are two purposes for the MLA analysis. In this study, I was interested in identifying the variables in collaborative discourse and epistemic practices that could predict individual student's performance in the posttest as a function of group-level interaction and teacher-level characteristics. As mentioned above, the sample includes two teachers, twenty groups, and eighty-two students. Each group varied from two to seven students. The following equation shows the general logic of the MLA method in this study.

$$Y = [\gamma + \sum \beta_G \times V_G + \sum \beta_T \times V_T] + [U_G + U_T + e]$$

In the MLA equation, Y represents the dependent variable (i.e., the Total B and F score). The Total behaviors plus functions were used as the predicted variable here because the variability in them relates to the depth of understanding. The combined model is the sum of two effects – the fixed effect and the random effect. In the above equation, the terms in the first bracket represent the fixed effect part and those in the second bracket represent the random effect part. In this study, the fixed variables included the coding categories in the collaborative discourse coding (including the subcategories (V_G) for students' conversations and the four categories of teacher's facilitation (V_T) in the group discourse) or those in the epistemic practice practices. The coefficient (β) represents how much contribution one unit of the fixed variable contribute to the change in the dependent variable. Thus, β_G denotes the specific coefficient for each group interaction variable, and β_T denotes the coefficient for each teacher's facilitating variable. In this study, there are three error terms at three levels: individual (e), group (U_G), and teacher (U_T), which represent random residual error variation in the average dependent variable among individual students, groups, and teachers respectively.

The multilevel model was constructed using the group-level interaction categories and teachers' facilitating categories as predictors of the dependent variable – Total B and F scores in the posttest. The PROC MIXED function in SAS software was used to run the multilevel models. The significant coefficient for the fixed variables would tell which characteristics in collaborative discourse and/or epistemic practices at the group level should be able to predict individual students' learning outcomes in the posttest.

Case Studies

Case studies are known as a triangulated research strategy. Case study methodology excels at adding strength to the findings of previous analyses by emphasizing detailed contextual analysis of a limited number of cases. As Yin (2002) notes, case studies should not be confused with pure qualitative research and they can be based on any mix of quantitative and qualitative evidence. In this research, the case studies include both quantitative analysis (i.e., the sequential analysis) and descriptive qualitative analysis.

In current research, there were two purposes for the case studies. First, it is used as a triangulated strategy to provide further evidence for the inferences drawn from previous quantitative analysis. In addition, it investigates the patterns that occurred in group interactions. The two high-achievement groups (Group 19 from Ms. W's classes and Group 8 from Mr. K's classes) were selected for qualitative comparison with the two low-achievement groups (Group 14 from Ms. W's classes and Group 10 from Mr. K's classes) based on two metrics: the group mean score of Total Behaviors and Total Functions in the posttests and their final understanding level of the Nitrogen Cycle. Specifically, all the groups were ranked according to their understanding level of the specific concept of Nitrogen Cycle, which was considered to be one of the fundamental concepts in understanding this domain. The groups with the highest understanding level (i.e., the examined level, level 4) of the Nitrogen Cycle were then ranked by the group mean score of behaviors and function in the posttests, which represented the extent of the expert understanding. The groups with the lowest understanding level of the concept of

Nitrogen Cycle (i.e., either the recognized level (level 1) or the explanatory level (level 2)) were ranked by the group mean score of total behaviors and functions in the posttests.

Sequential Analysis. Sequential analysis has been used to examine conversational patterns in many studies, such as studies on children at play, mother infant play, and on human-computer interaction. Recently, researchers claim that this method is the "missing factor" in CSCL research. Koschmann (1998) argues that the dialogic theory (Bakhtin, 1981) provides a theoretical framework for conceptualizing and operationalizing group interaction in collaborative learning. He regards learning as a transactional process in which a transaction takes place between the learner and the situated context. This view offers a new and powerful framework for analyzing learning and calls for a new analysis method to appreciate the changes taking place both within the individual and the social environment. Sequential analysis is a method that meets the demands in CSCL research.

One major metric involved in sequential analysis is *transitional probabilities* (Jeong, 2008). Transitional probabilities are computed by tallying the frequency and relative frequency of a particular discourse turn in reply to a previous discourse turn and by reporting the results in a frequency matrix. In sequential analysis, the number of transitions of one event to the next is tested for significance with regard to the expected number of transitions of that particular type based on the distribution of probability. To determine whether a pattern exists in the collaborative discourse, the transitional probability will be judged if it is significantly higher or lower than expected by the calculated z-scores in a *z*-score matrix.

In this study, I used the computer program *Multiple Episode Protocol Analysis* (MEPA) developed by Gijsbert Erkens (2005) to conduct sequential analysis by computing the frequency, transitional probability, and z-score for each event pair. MEPA is a program for the analysis of collaborative discourse protocols, which allows for executing analysis of coded verbal and non-verbal data using built-in quantitative and qualitative methods. It can import coded protocols from excel files, calculate frequencies of codes, perform sequential analyses, construct cross-tabulations with associative variables, and create visual transition diagrams resulted from sequential analysis. In the resulting transition diagrams, only significant events are shown.

Qualitative Analyses. The qualitative analyses take a closer look at the four groups' transcripts and compare some telling characteristics of them. Example excerpts from the transcripts will be illustrated to triangulate and exemplify the results from the previous sequential analysis. Chronologically-oriented Representations of Discourse and Tool-related Activity (CORDTRA) diagrams for the four groups' coded transcripts were created to illustrate students' group activities during their use of simulation models. CORDTRA methodology allows researchers to visualize the group dynamics that emerge during the collaborative activity (Hmelo-Silver, 2003; Luckin, Plowman, Laurillard, Stratfold, Taylor, & Corben, 2001). The diagrams were created with Microsoft Excel software. The numbers along the *x*-axis refer to the line number of each conversational turn. Along the *y*-axis are the numbers that represent each coding categories (for collaborative discourse coding and epistemic practice coding) and corresponding speakers. The entries in the diagram refer to speakers and instances of discourse and epistemic practices indicated by the coding category on the *y*-axis at the turn indicated by the position along the *x*-axis. Another beneficial function in CORDTRA representation is that it allows you zoom in to focus on details of certain interesting conversations. The details of how to read the CORDTRA representation would be introduced in Chapter 5 where the actual example CORDTRA representations were illustrated and interpreted.

In addition to CORDTRA diagrams, for each group, one example excerpt was analyzed qualitatively to explore how groups used the simulation tools to understand the concept of Nitrogen Cycle. Collaborative discourse and epistemic practice patterns were discusjjsed for each group. Also, the groups were compared to see how they used the tools differently and what different patterns were identified during group interaction.

Summary of Study Design and Data Analyses

Analytic procedures were undertaken to answer the research questions of this study. Figure 6 summarizes the study procedures and the analytic framework. As marked in italics in Figure 6, the design of each step of the data analysis was to pursue one or more research questions.

To revisit the research questions, the purpose of the study was to test the collaborative scientific conceptual change model by examining the relationships between the patterns of student collaborative discourse, the epistemic practices, and the trajectories of collaborative scientific conceptual change. There are four research questions:

1. What conceptual change occurs as a result of participating in a technology-enhanced curriculum unit for learning about aquarium ecosystem?
2. What collaborative discourse patterns emerge during the collaborative use of computer tools and how are they related to student conceptual change?
3. What epistemic practice patterns emerge during the collaborative use of computer tools and how are they related to student conceptual change?

4. What are the trajectories of collaborative scientific conceptual change?

As illustrated in Figure 6, the mixed ANOVA analysis and the qualitative descriptive analysis addressed the first research question. The one-way ANOVA test and the MLA analysis were to answer the second and third research question. The sequential analysis, CORDTRA charts combined with the qualitative analysis were to explore the last three research questions. The following chapter reports the results of different analysis methods.

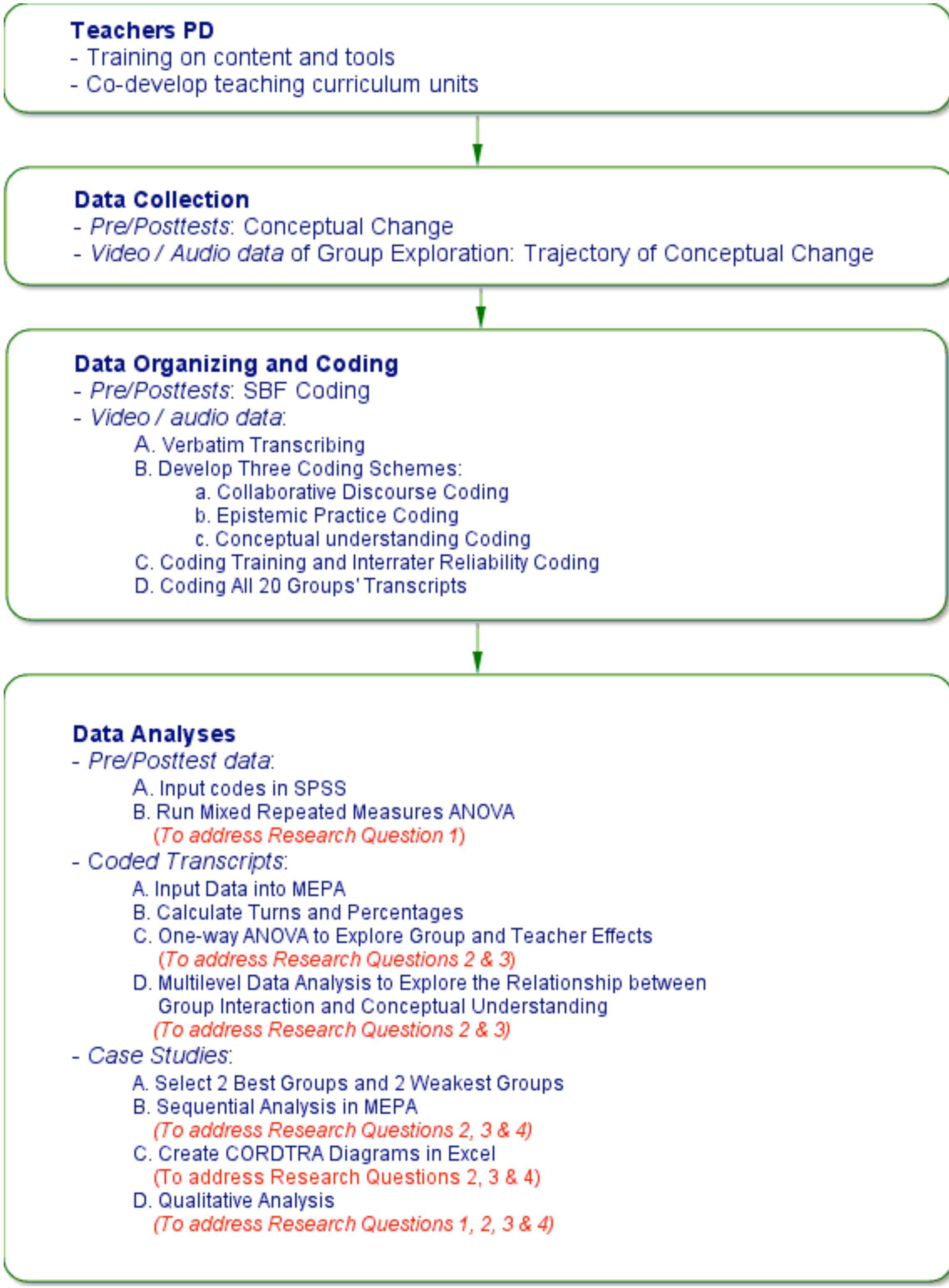

Figure 6. Summary of Study Procedures and Date Analyses Framework.

CHAPTER 4

QUANTITATIVE RESULTS

The results are divided into five sections. The first section reports on the groups' learning achievements as well as the differences in group interactions. The second section reports on the results of sequential analysis. The third section reports on the results of the multilevel analysis. Finally, the fourth section reports on the results of qualitative analyses by comparing the transcripts of two high-achievement groups and two low-achievement groups with respect to their trajectories of conceptual understanding. All the statistical significance reported in this study is at .05.

Learning Achievement and Variability across Groups

As reported elsewhere (Hmelo-Silver, Liu, Gray, Finkelstein, & Schwartz, 2007), we conducted a mixted 2x3x2 ANOVA with teacher (Ms. W and Mr. K) as the between-subject factor and time (pre and post) and SBF level (S, B, and F) as within subject factors. Table 3 shows the means and standard deviations of the SBF scores of two classroom settings for pre and post tests. There were teacher x time x SBF interactions in the aspects of structures and functions but not for behaviors (for structure, $F(1,143) = 6.06$, $p = .015$; for function, $F(1,143) = 5.27$, $p = .023$). Specifically, students in teacher A's classes achieved more in structural and functional knowledge than students from teacher B's classes did. For both teachers' classrooms, there were significant learning gains in structures, behaviors, and functions (for Ms. W, $F(1,69) = 38.01$, $p < .001$, $F(1,69) = 24.48$, $p < .001$, $F(1,69) = 285.56$, $p < .001$, respectively; for Mr. K, $F(1,74) = 15.20$, $p < .001$, *F(1,74)*=71.23, *p*<.001, *F(1,74)*=62.64, *p*<.001, respectively). This suggests that after using the RepTools students understood more about structures, behaviors, and functions in their posttests than in their pretests. The effect sizes for both teachers' classroom settings are either moderate or large in terms of SBF (for Ms. W, *d*=.78, *d*=.77, *d*=1.97, respectively; for Mr. K, *d*=.54, *d*=1.23, *d*=1.19, respectively).

Table 3. Means and standard deviations of pre- and posttest SBF scores.

Teacher	Time	Structure	Behavior	Function
Ms. W	Pretest	8.53 (1.68)	4.11 (1.82)	4.50 (2.24)
	Posttest	9.66 (1.17)*	5.69 (2.22)*	9.13 (2.46)*
Mr. K	Pretest	9.32 (1.10)	4.91 (1.54)	7.10 (2.58)
	Posttest	9.88 (0.97)*	7.11 (2.00)*	10.53 (3.14)*

As expected, the results showed great variability in the ways that students interacted within focal groups. To examine the group effect on students' learning outcomes, a mixed 2x20x2x3 ANOVA test was conducted to compare the mean SBF scores in the pre-/posttests.

Table 4 shows the means and standard deviations of the SBF scores of the focal groups. The asterisks in the table represents where the statistical significances are. There were group x time x SBF interactions for behaviors, but not for structures and functions (for behaviors, *F(1, 18)* = 2.33, *p*= .007). Consistent with previous analyses on the aggregated data, for all students in the focal groups, there were significant learning gains in structures, behaviors, and functions (*F(1, 62)*=19.11, *p*<.001, *F(1, 62)*=65.84, *p*<.001, *F(1, 62)*=120.95, p<.001, respectively).

Table 4. Group Means and Standard Deviations of SBF in Pre-/Posttests.

Teacher	Group	Pretest			Posttest		
		S	B	F	S*	B*	F*
Mr. K	1	9.33 (1.53)	5.00 (2.65)	6.00 (1.73)	9.67 (.58)	5.33 (1.15)	8.67 (1.15)
	2	10.00 (.00)	3.67 (2.08)	8.33 (2.89)	10.67 (1.15)	8.33 (2.08)	12.00 (2.00)
	3	9.80 (.45)	5.00 (1.00)	8.40 (2.07)	10.20 (.45)	8.60 (.89)	11.80 (1.30)
	4	9.60 (1.14)	4.80 (1.79)	8.20 (1.10)	8.80 (.84)	7.40 (1.95)	10.80 (3.63)
	5	10.33 (.58)	6.67 (2.52)	8.33 (1.53)	9.67 (1.53)	6.67 (1.15)	12.00 (.00)
	6	9.75 (.50)	5.00 (.82)	7.75 (2.22)	10.25 (.50)	6.50 (1.73)	9.25 (2.22)
	7	10.00 (.00)	4.50 (.58)	5.25 (.96)	10.25 (.50)	8.00 (2.16)	10.50 (4.36)
	8	9.50 (1.00)	5.00 (1.41)	7.50 (1.29)	10.25 (.50)	9.25 (2.87)	12.75 (1.71)
	9	9.25 (.50)	5.00 (1.41)	9.50 (4.20)	10.50 (1.00)	7.50 (.58)	12.75 (4.11)
	10	9.20 (.84)	4.60 (.55)	6.00 (2.55)	9.60 (.89)	5.20 (1.10)	7.20 (3.49)
Ms. W	11	9.00 (1.73)	4.33 (3.21)	3.00 (3.46)	10.00 (1.00)	5.67 (2.31)	10.00 (3.61)
	12	8.50 (2.38)	2.50 (.58)	3.50 (.58)	9.75 (1.50)	6.25 (3.20)	9.50 (2.65)
	13	8.33 (1.15)	3.00 (1.00)	3.67 (1.53)	9.67 (.58)	5.00 (1.00)	9.00 (1.00)
	14	9.60 (.55)	4.00 (.71)	6.00 (2.12)	10.40 (.89)	4.80 (2.05)	8.80 (1.48)
	15	8.71 (1.50)	4.71 (2.21)	4.29 (2.29)	9.43 (1.51)	5.00 (2.45)	8.86 (2.27)
	16	9.33 (1.15)	4.67 (1.53)	5.00 (2.00)	10.00 (1.00)	4.67 (.58)	7.67 (4.04)
	17	7.67 (2.52)	4.33 (3.51)	3.33 (2.31)	9.67 (1.53)	7.00 (3.46)	11.00 (2.65)
	18	8.25 (3.10)	3.50 (1.91)	7.25 (1.71)	10.00 (1.15)	8.50 (3.11)	11.75 (.96)
	19	8.40 (1.82)	4.60 (2.88)	4.80 (2.68)	9.00 (1.58)	5.40 (1.67)	9.60 (3.21)
	20	8.20 (1.92)	4.20 (1.92)	3.80 (2.49)	8.60 (.55)	4.20 (1.48)	7.00 (1.87)

$^{*}p < .05$

To compare whether there were differences in group interaction across groups, the percentage for each category in the collaborative discourse and the epistemic practice coding schemes were calculated. In addition, the codes for each conceptual understanding level were counted for each group. Table 5, 6 and 7 respectively illustrate the descriptive data for the collaborative discourse categories, the epistemic practice categories, and the conceptual understanding level codes for group 1 – 10 (taught by Mr. K). Table 8, 9 and 10 illustrate the descriptive data for group 11 – 20 (taught by Ms. W).

To examine the variability in how students interacted in their group activities, one-way ANOVA test was applied with “Group” as the independent variable, and the percentage of each coded categories as the dependent variable. For the collaborative discourse coding categories, an initial one-way ANOVA test showed significant differences in the percentages of the following coding categories: Describe Observation ($F(19, 62)=2.27$, $p=.008$), Direct ($F(19, 62)=2.93$, $p=.001$), Evaluate ($F(19, 62)=2.26$, $p=.008$), Plan ($F(19, 62)=5.21$, $p<.0001$). For the epistemic practice coding categories, the ANOVA results found significant differences in the following categories: Basic Knowledge Construction ($F(19, 62)=1.77$, $p=.047$), Observe ($F(19, 62)=2.16$, $p=.012$), Check Knowledge Validity ($F(19, 62)=3.54$, $p<.0001$), Design Experiment ($F(19, 62)=5.51$, $p<.0001$), Give Feedback ($F(19, 62)=2.22$, $p=.01$), Modify Knowledge ($F(19, 62)=3.81$, $p<.0001$).

To compare the difference in how groups interacted in two different classroom settings, one-way ANOVA test was applied with “Teacher” as the independent variable, and the percentage of each coded categories as the dependent variable. For the collaborative discourse coding categories, an initial one-way ANOVA test showed a significant results in the percentages of the following coding categories: Disagree ($F(1, 80)=4.75$, $p=.032$), Generate Theory ($F(1, 80)=4.10$, $p=.05$), Share Knowledge ($F(1, 80)=4.32$, $p=.041$), Warranted claims ($F(1, 80)=4.08$, $p=.047$), Plan ($F(1, 80)=5.67$, $p=.02$), Monitor ($F(1, 80)=5.07$, $p=.027$). The differences in disagreement, generating theories, sharing knowledge, and warranting claims were all in favor of Mr. K's groups. The differences in planning and monitoring learning were in favor of Ms. W's groups. For the epistemic practice coding categories, the ANOVA results found significant differences in the following categories: Design Experiment ($F(1, 80)=21.19$, $p<.0001$), Observe ($F(1, 80)=4.24$, $p=.043$), Check Knowledge Validity ($F(1, 80)=11.51$, $p=.001$), Coordinate Theory-Evidence ($F(1, 80)=18.50$, $p<.0001$). The differences in these categories were all in favor of Mr. K's groups except for designing experiments. Table 5, 6, 8 and 9 displayed the mean percentages and standard deviations of significant coding categories in the two classroom settings.

Tables 7 and 10 showed the coded conceptual understanding levels for all the twenty focal groups. As mentioned before, in the conceptual understanding coding, a new code was given either when there was a new topic occurred or there was a new level of understanding level occurred in the group discourse. The topics include both graphic representations in the simulations models (e.g., different colors of dots and patches) and the conceptual representations (e.g., ammonia, nitrite, nitrate). As shown in table 7 and table 10, the total of codes of conceptual understanding levels varied by groups. Several possible reasons resulted in such variability. First, different groups covered different amount of topics in their discourse. For example, some groups did cover the concepts such as energy flow and cellular respiration in the fish tank and others did not. Second, the groups differed in the trajectories of conceptual development in the way of connecting or jumping among topics. Some groups' discourse made more relational connections between concepts. But other groups' discourse kept changing from one topic to another but stayed at low levels of understanding levels. In other words, the frequency for each conceptual understanding level for the groups depends on the change in topics as well as in the level of understanding of one specific topic. In addition, this coding scheme did not weigh the difficulty in understanding various concepts involved in the system. For example, understanding the nitrogen cycle was treated as the same weight as the concept of fish food. Therefore, it was not appropriate to tell how deep the groups' holistic understanding of the aquarium ecosystem was from the frequencies in table 7 and 10. For example, in table 7, even though group 5's frequency for level 4 understanding ranked first among all the ten focal groups in Mr. K's classes, it does not necessarily indicate this group achieved the highest level of the system understanding. To be able to identify the group's performance, the concept of "nitrogen cycle" was selected as the most difficult concept based on the classroom observation. The final understanding level of this concept plus students' performance in the posttest were the two criteria that I used for identifying the high or low achievement groups in the case study.

However, the significant one-way ANOVA results by itself was not sufficient because it returns a significant result when it finds a difference between *any* of the independent variable means and the aggregate mean. In this study, the one-way ANOVA test results did show statistically there are significant differences in many coding categories as well as in the posttests when using the group and teacher as the independent variable. However the results provide little information concerning the relations between those coding categories and the learning outcomes. The Multilevel Data Analysis was conducted to identify which kinds of group interaction affect students' learning outcomes.

Table 5. Mean percentage of collaborative discourse coding variables for group 1-10.

		Mr. K										
		G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	Total
Student%	Fact Question	3.82	5.52	6.33	4.99	3.13	4.92	7.41	2.39	3.30	9.58	51.39
	Explanation Question	5.73	7.14	3.16	6.65	3.61	7.38	4.68	5.87	5.22	3.28	52.72
	Confirm Question	5.34	7.14	4.64	4.43	4.57	4.92	2.34	4.78	3.30	2.99	44.45
	Directing Statement	1.53	2.92	1.05	2.49	0.96	1.64	3.90	1.52	0.27	0.30	16.58
	Agree	3.82	1.62	4.64	3.60	1.92	1.09	3.12	4.35	1.37	0.30	25.83
	Disagree	0.76	0.32	2.32	0.83	2.88	2.19	4.29	2.17	1.65	0.90	18.31
	Share Knowledge	4.58	1.95	2.74	3.05	5.05	1.64	1.95	5.43	5.49	1.20	33.08
	Describe Observation	9.16	24.68	29.54	21.33	26.68	26.78	30.02	34.57	24.73	26.95	254.44
	Retrieve Prior Knowledge	6.87	1.62	3.16	4.71	2.40	5.74	5.26	2.39	1.65	3.29	37.09
	Generate Theory	9.16	12.01	15.19	14.40	12.02	17.76	12.87	7.39	17.31	15.87	133.98
	Paraphrase	3.44	1.95	2.32	4.43	3.61	3.28	3.90	4.35	1.37	1.80	30.45
	Warranted claim	17.94	8.44	7.17	11.08	12.02	6.56	6.04	10.43	8.52	10.48	98.68
	Identify Conflict	2.29	0.97	0.84	0.83	0.96	2.19	0.39	0.87	3.30	0.90	13.54
	Plan	4.20	8.44	4.85	3.05	10.10	3.28	5.07	5.43	13.19	10.48	68.09
	Monitor	9.54	4.55	5.27	7.76	3.85	6.56	4.09	3.04	3.30	4.19	52.15
	Review	9.16	1.62	1.48	3.60	4.57	1.64	3.12	3.70	2.47	4.19	35.55
	Evaluate	1.53	4.22	3.80	0.83	1.20	2.19	0.78	0.22	2.75	2.10	19.62
	Miscellaneous	1.15	4.87	1.48	1.94	0.48	0.27	0.78	1.09	0.82	0.30	13.18
Facilitation%	Educational Statement	33.01	44.79	31.03	41.75	47.83	32.31	21.65	31.03	28.95	43.08	355.43
	Performance Statement	9.71	9.38	0	1.94	2.17	1.54	4.12	5.17	0	1.54	35.57
	Open Question	43.69	15.63	46.55	33.01	34.78	32.31	42.27	48.28	26.32	29.23	352.07
	Closed Questions	13.59	30.21	22.41	23.30	15.22	33.85	31.96	15.52	44.74	26.15	256.95
Total Turns		366	443	533	464	462	432	610	518	402	399	

Table 6. Mean percentage of epistemic variables for group 1-10.

		Mr. K										
		G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	Total
Epistemic Practice%	Basic Knowledge Construction	5.73	3.25	4.85	5.26	2.40	5.19	5.26	3.04	5.22	9.88	50.08
	Observe	12.21	44.81	55.49	54.57	49.28	56.83	48.73	46.52	44.78	49.70	462.92
	Predict	8.78	4.87	5.70	5.26	8.41	3.55	8.38	5.43	8.79	2.10	61.27
	Design Experiment	3.44	6.49	4.43	2.77	10.10	2.46	10.33	7.83	12.91	12.57	73.33
	Check Knowledge Validity	8.40	3.90	1.27	1.39	2.40	2.19	0.97	3.26	3.85	0.30	27.93
	Coordinate Theory-Evidence	12.60	8.12	7.38	8.03	8.65	10.93	6.24	9.35	9.07	10.18	90.55
	Modify Knowledge	9.16	0.32	1.27	0.28	1.20	0.27	0	0.87	1.37	1.20	15.94
	Exchange Knowledge	33.21	18.18	13.29	18.56	16.11	16.39	18.71	20.87	12.09	12.28	179.69
	Give Feedback	4.96	5.19	4.64	1.94	0.96	1.91	0.97	1.74	1.10	1.50	24.91
	Miscellaneous	1.53	4.87	1.69	1.94	0.48	0.27	0.39	1.09	0.82	0.30	13.38
Total Turns		366	443	533	464	462	432	610	518	402	399	

Table 7. Frequencies for each conceptual understanding level for group 1-10.

		Mr. K										
		G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	Total
Conceptual Understanding	Level 1: Recognizing	19	16	27	13	13	9	24	14	27	31	193
	Level 2: Explanatory	35	19	36	30	37	41	37	55	41	32	363
	Level 3: Critiquing	9	2	10	6	3	3	4	2	5	2	46
	Level 4: Examined	9	5	8	12	14	8	7	2	3	2	70

Table 8. Mean percentage of collaborative discourse coding variables for group 11-20.

		Ms. W										
		G11	G12	G13	G14	G15	G16	G17	G18	G19	G20	Total
Student%	Fact Question	3.45	1.01	8.15	9.25	3.22	5.42	7.33	4.64	3.40	14.04	59.91
	Explanation Question	6.21	6.03	5.19	5.25	5.45	3.73	4.19	6.19	8.84	7.89	58.97
	Confirm Question	2.07	3.02	5.19	4.50	5.69	3.39	5.24	1.55	2.04	2.63	35.32
	Directing Statement	2.07	1.51	1.48	7.25	7.43	0	0.52	0	0	0.88	21.14
	Agree	2.07	10.55	1.85	2.25	2.48	5.08	4.71	6.70	2.04	1.75	39.48
	Disagree	1.38	0	1.11	1.00	1.73	0.34	1.05	0	2.04	1.75	10.4
	Share Knowledge	5.52	9.55	2.22	5.25	4.70	2.71	4.19	5.67	6.12	10.53	56.46
	Describe Observation	25.52	15.08	31.85	27.00	21.78	34.24	20.94	34.54	21.09	12.28	244.32
	Retrieve Prior Knowledge	4.83	2.01	2.59	4.50	1.98	2.03	2.09	4.12	2.04	6.14	32.33
	Generate Theory	7.59	7.54	10.37	7.00	9.90	10.51	13.61	11.86	17.01	7.89	103.28
	Paraphrase	2.76	6.53	2.59	3.25	5.69	3.39	1.57	1.55	8.84	5.26	41.43
	Warranted claim	2.76	9.05	6.67	7.50	6.44	6.10	7.85	9.28	8.84	5.26	69.75
	Identify Conflict	0.69	0	2.22	1.75	1.24	1.69	0.52	0.52	0.68	0	9.31
	Plan	16.55	15.58	14.07	6.00	6.19	11.86	17.80	6.70	8.84	8.77	112.36
	Monitor	4.14	3.52	2.22	2.00	6.19	2.71	5.76	1.55	2.04	3.51	33.64
	Review	1.38	3.02	0.74	4.25	2.97	4.41	3.66	3.61	5.44	1.75	31.23
	Evaluate	5.52	4.02	0.74	0.25	2.23	0.68	1.05	1.55	0.68	0.88	17.6
	Miscellaneous	5.52	2.01	0.74	1.75	4.70	1.69	0	0	0	0.88	17.29
Facilitation%	Educational Statement	15.38	12.50	42.86	16.22	27.08	33.33	41.18	48.00	33.33	21.43	291.31
	Performance Statement	0	0	0	5.41	25.00	0	5.88	0	0	7.14	43.43
	Open Question	53.85	37.50	50.00	24.32	18.75	58.33	23.53	16.00	40.00	7.14	329.42
	Closed Questions	30.77	50.00	7.14	54.05	29.17	8.33	23.53	36.00	26.67	64.29	329.95
Total Turns		158	215	284	438	457	307	208	219	162	119	

Table 9. Mean percentage of epistemic variables for group 11-20.

		Ms. W										
		G11	G12	G13	G14	G15	G16	G17	G18	G19	G20	Total
Epistemic Practice%	Basic Knowledge Construction	2.07	2.01	4.80	3.50	5.20	7.12	8.90	6.70	10.20	10.53	61.03
	Observe	36.55	27.14	49.63	38.50	37.87	51.19	31.94	46.39	31.29	24.56	375.06
	Predict	8.28	5.53	5.19	7.00	2.48	7.46	11.52	4.64	14.29	14.04	80.43
	Design Experiment	18.62	20.10	18.89	22.25	9.41	15.25	23.56	10.82	14.97	14.04	167.91
	Check Knowledge Validity	0.69	0	0.37	1.00	1.73	0.34	1.05	0	0.68	0	5.86
	Coordinate Theory-Evidence	2.07	3.02	4.44	5.50	7.92	4.07	2.09	4.64	6.12	0.88	40.75
	Modify Knowledge	5.52	0	0.37	0.50	0.99	0.68	1.05	0	0.68	1.75	11.54
	Exchange Knowledge	22.07	36.68	15.19	18.75	27.23	11.86	17.80	25.26	21.77	32.46	229.07
	Give Feedback	4.14	4.02	0.37	0.75	1.98	0.34	2.09	1.55	0	0.88	16.12
	Miscellaneous	0	1.51	0.74	2.25	5.20	1.69	0	0	0	0.88	12.27
Total Turns		158	215	284	438	457	307	208	219	162	119	

Table 10. Frequencies for each conceptual understanding level for group 11-20.

		Ms. W										
		G11	G12	G13	G14	G15	G16	G17	G18	G19	G20	Total
Conceptual Understanding	Level 1: Recognizing	6	4	16	14	13	16	16	19	6	11	121
	Level 2: Explanatory	12	27	31	41	34	30	15	26	18	17	251
	Level 3: Critiquing	0	0	2	4	1	2	2	2	2	2	17
	Level 4: Examined	0	0	0	3	6	4	0	2	9	1	25

Multilevel Data Analyses Results

The goal of the MLA method was to explore how group-level interactions (e.g., collaborative discourse and epistemic practices) and teacher's facilitation (e.g., educational statement, performance statement, open questions, and closed questions) affected students' learning at both individual and group levels. In the MLA model for measures of collaborative discourse predicting individual Total B and F score (TotalBF), the covariance parameter estimates for Teacher, Group within Teacher, and Individual parameter were 3.68, 6.50, and 9.87 respectively. These estimates show the how much effect one parameter has on the predicted variable. Therefore, the results indicated that there were group and teacher effects on individual students' learning. The group effect was greater on individual student learning than the teacher effect. For all the measures of collaborative discourse and teacher's facilitation, only the measure *Warranted claims* was a significant predictor ($\beta=95.82$, $t(58)=2.16$, $p=.03$). This indicates that the more warranted claims one student produces in the group discourse, the higher mean score the group would achieve in the posttest, and vice versa. In addition, the collaborative discourse feature "Evaluate" was marginally significant ($\beta=173.83$, $t(58)=1.95$, $p=.06$).

When using the measures of epistemic practices to predict individual TotalBF score, the covariance parameter estimates for Teacher, Group within Teacher, and Individual parameter were 5.58, 6.32, and 8.75 respectively. Three measures were found as significant predictors for TotalBF: Coordinate Theory-Evidence ($\beta=104.19$, $t(72)=2.74$, $p=.01$), Modify Knowledge ($\beta= -144.16$, $t(72)= -2.11$, $p=.04$), and Predict ($\beta=54.80$, $t(72)=2.18$, $p=.03$). It was interesting to find that modifying knowledge showed negative predicting role in student learning. However the distribution of collaborative discourse also show that groups seldom identified cognitive conflict in their group discussion. Thus without replicatory results, one can not overgeneralize.

Summary of Quantitative Results

In summary, there are three major findings in the quantitative analyses. First, consistent with the aggregated data analyses, the mixed ANOVA analyses found significant learning gains for students in the focal groups between the pre and posttests. There was also an interaction between group factor and the time factor. Specifically, the learning gains in understanding behaviors were different across groups.

The second major finding out of the quantitative analyses was that there was significant variability among groups in terms of their learning gains in understanding the system behaviors, the characteristics of collaborative discourse, epistemic practices, and conceptual understanding levels. Across the total twenty focal groups, they differed in the distribution of discourse constituents. The variability in group discussion mainly lay in describing observed phenomena, planning, directing, and evaluating. As for epistemic practices that groups employed, the difference showed in building basic knowledge construction, observing, designing experiment, giving feedback, checking knowledge validity, and modifying knowledge.

Consistent with the impression from class observations, the huge teacher differences were mirrored in student performance and group interaction in the focal group samples, but not in actual learning outcome for the classes as a whole. Particularly, the comparison between the total turns that each group produced showed that students tended to talk more in Mr. K's classes than in Ms. W's classes. Furthermore, results showed that students in the focal groups from Mr. K's classes demonstrated more knowledge of behaviors and functions in the posttests than those in Ms. W's classes.

The results also showed great variability in group interactions. As for the characteristics of collaborative discourse, the focal groups showed significant difference in many aspects, such as disagreement, generating theory, sharing knowledge, proposing warranted claims, planning and monitoring learning. As to epistemic practices, several features, such as designing experiments, observing, checking knowledge validity, coordinating theory-evidence, were significantly distinct across two classroom settings.

The third major finding came from the MLA modeling. The results confirmed the significant group and teacher effect on individual students' conceptual understanding. The function of MLA modeling allowed identifying what features in collaborative discourse or epistemic practice predict students' learning outcomes. The results showed that the warranted claim was the most important predictor in collaborative discourse, and features, such as coordinating theory-evidence, modifying knowledge, and predicting, in students' epistemic practices could predict students' individual performance in the posttest. These results are enlightening and are consistent with the collaborative scientific conceptual framework, which stresses the importance of high quality collaborative discourse and scientific epistemic practices in the process of conceptual change.

CHAPTER 5

CASE STUDY RESULTS AND DISCUSSION

The purpose of the case studies was to provide further evidence for the inferences drawn from previous quantitative analysis and to identify the patterns occurred in group interactions that may have effect on the quality of collaborative activities. Four groups (including two high-achievement and two low-achievement) were selected based on the group mean score of Total B and F scores and their final understanding level of the Nitrogen Cycle, which is essential for understanding the whole system. The following sections report the findings from the frequencies, CORDTRA analysis and sequential analysis. Groups 8 and 19 were the two high achieving groups; groups 10 and 14 were the low achieving groups. Groups 8 and 10 were from Mr. K's classes and groups 19 and 14 were from Ms. W's classes.

Differences in Frequencies across Groups

Figure 7 illustrates the bar graph for the variables, in which the differences lay, across the four groups (see in table 5, 6, 8 and 9 for the descriptive statistics for each group). There were obvious differences across the four groups in frequencies of the following categories: paraphrase, explanation question, fact question, share, and warranted claims. As for the epistemic practice coding variables, the differences lay in the frequency of coordinating theory-evidence, design experiment, exchange knowledge, and predict. The results converged with the MLA analyses, which found that warranted claims, coordinating theory-evidence, and predicting were significant predictors for students' posttest scores.

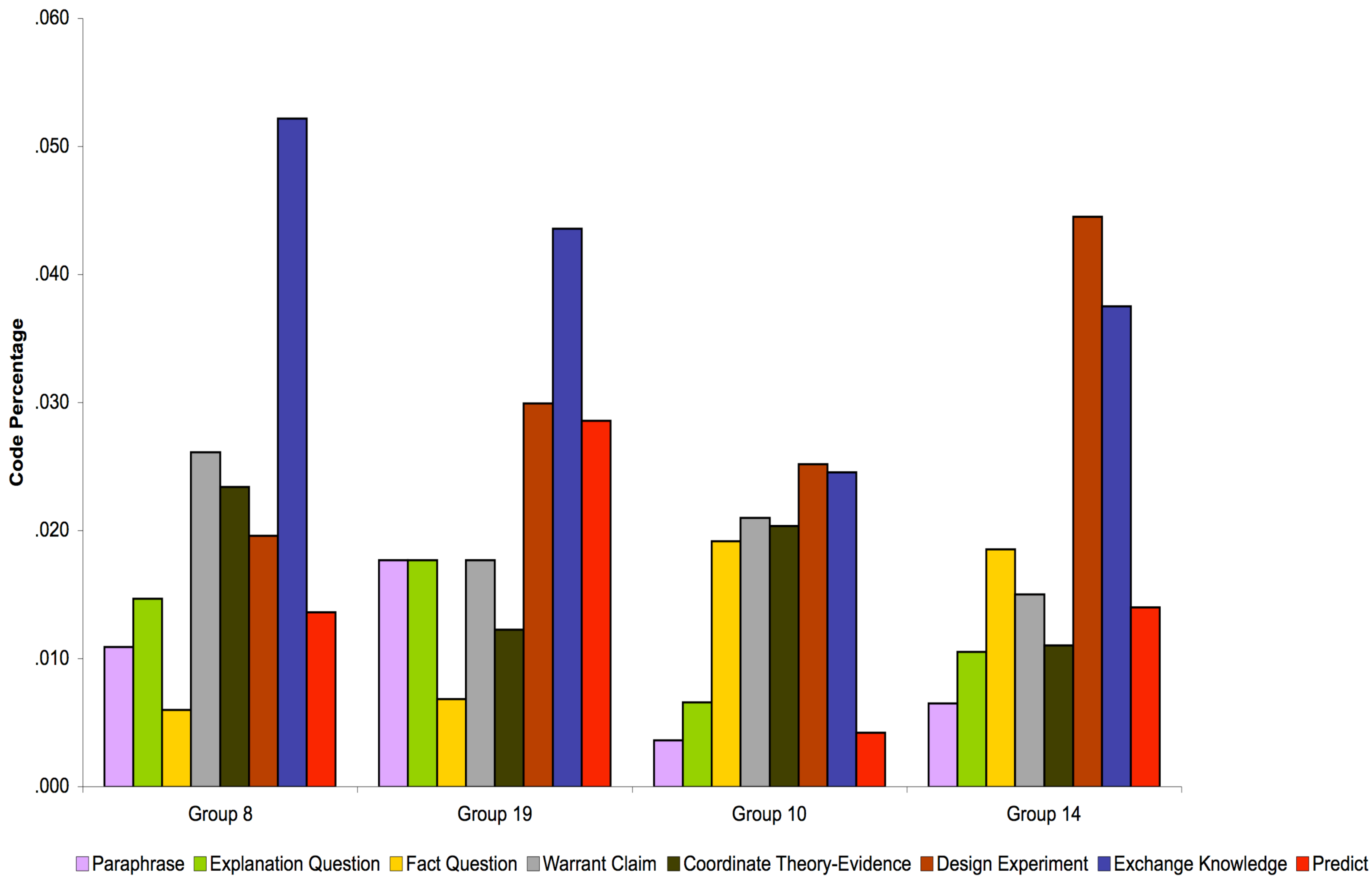

Figure 7. Percentage Frequency across Cases

The differences in the groups' frequency distribution suggest the high-achievement groups and the low-achievement groups conduct their conversations differently. The results showed that compared to the two low-achievement groups, both high-achievement groups made more efforts to paraphrase, ask explanation questions and generate warranted claims. The low-achievement groups asked more fact questions.

When paraphrasing, students restated peers' ideas in their own words. It allows students opportunities to clarify and check how well they understand each other, fill in gaps between the distributed knowledge, thus build on each other's knowledge to achieve shared knowledge (King, 2002). For example, in Group 19, Eva started to notice the function of graph in the Nitrogen Cycle simulation model, and said to the group, "The change wait a minute, the number change of the ammonia, nitrite, nitrate. The graph shows what is going on." Another student, Hima paraphrased Eva's statement by saying, "It shows us what is going on in the tank… like it shows us the ammonia and the bacteria." On the one hand, Hima parroted Eva's idea that the graph could help understand what was happening in the model. On the other hand, as Eva illustrated ammonia, nitrite and nitrate as the components included in the simulation model, Hima added his own understanding that the model was also related to bacteria, thus suggesting that he had reorganized his thinking by incorporating the concept into his existing knowledge.

It was not surprising to see that the high-achievement groups made efforts to ask explanation questions and generate warranted claims, since one was the other's consequence. Different types of questioning may provide different opportunities for students to learn. Further, the questions generated help scaffold the learning process and actively involve students in thinking deeply. Explanation questions required peer students to justify their responses, thus engaged the group in the scientific practices of explanation and argumentation and provided an invitation for the group to generate warranted claims and check the accountability of proposed ideas (Duschl, Schweingruber, & Shouse, 2007). In CSCL learning environments, thought-provoking questions (i.e., explanation questions) and warranted claims engage students in "minds-on" activities as they integrate the information from the computer tools with prior knowledge, thus leading students to construct new knowledge. In addition, the computer tools (e.g., simulation models) provide opportunities for students think about "why" things happen. To illustrate, the following excerpt from Group 8 shows how an explanation question drove warranted claims and affected the tool-based activities.

139. Brad: Look at this, why is there so many small fish?

140. Ada: Increasing the water quality increases spawning. So let's leave everything alone.

141. Ada: So you guys want to try what the higher one (water quality) does. Okay, ready?

142. Ada: Look at the spawn, is like 1460 right now.

In the dialogue above, based on what he saw in the Fish Spawn simulation model, Brad asked an explanation question (Turn 139), "why is there so many small fish?" This question drove Ada's warranted claim (Turn 140), "Increasing the water quality increases spawning." And Ada continued to run an experiment in the model to test his justification. This example illustrated how the simulation model mediated students' high-level thinking by stimulating explanation questions and affording opportunities to test one's warranted claims.

In contrast to explanation questions, the answers to fact questions are straightforward and largely oriented towards retrieving declarative knowledge and engaged less cognitive activities. That is, fact questions may only stimulate students to search information in their existing knowledge and they may fail to make causal connections. In simulation-based learning, students often come up with a lot of fact questions, such as "what is the yellow?", "what is the blue?" "What just happened?" These questions do stimulate students to describe their observation or even come up with a theory. However, the fact questions failed to help students develop causal relations between what they observed and the generated theory. The following excerpt from Group 14 illustrates a sequence of several fact questions and answers among students.

116. Chris:	yea … yellow nitrate, the white is what?
117. Gabby:	Nitrite, the yellow.
118. Chris:	Red is ammonia, and that was like really high in the beginning
119. Gabby:	Look at the yellow thing
120. Chris:	Yea. Wait does it show the fish or no?
121. Gabby:	No.
122. Chris:	It just die, whatever. Oh my god.

Here in the above dialogue, Chris asked two fact questions. The question "the white is what?" (Turn 116) was not answered at all. And the answer to the second question "does it show the fish or no?" (Turn 120) was one word "No" (Turn 121) without elaboration. This example indicated that unlike explanation questions, fact questions failed to ignite discussion thus failed to arouse active engagement in thinking.

The differences across high-achievement and low-achievement groups in epistemic practices lay in predicting, designing experiment, coordinating theory-evidence, and exchanging knowledge. As shown in figure 7, the high-achievement groups engaged in more practices like predicting, designing experiments, and coordinating theory-evidence during the collaborative activities. These are sophisticated epistemic practices that scientists use to conduct scientific investigations. To some extent, the results challenge the assertion that few students see science as a process of building and testing models and theories (Carey & Smith, 1993; Driver, et al, 1996; Linn & Songer, 1993), because both high-achievement groups proved themselves to be able to "talk" and "do" science.

To illustrate, an example from Group 8's discussion presented how this group of students used the simulation tools to explore science.

130. Ada: The water quality do nothing to the fish ...

131. Brad: I think that it will go up in like a second…

132. Ada: If you increase the number of pspawn, the water quality goes down. It's negative now.

133. Ada: The water quality decreases because of the population.

134. Brad: Try it.

135. Ada: Look at this, look at this. It goes down to zero, right?

136. Ada: Negative 400.

137. Brad: The water quality decreases.

138. Siddarth: Yes, it did make sense. If you increase the filter flow the water

gets clean, and then it kills all the things that kill the fishes.

At the beginning, the students presented alternative hypotheses on "water quality". Ada at first predicted that water quality had nothing to do with fish (Turn 130). Brad predicted the water quality should go up (Turn 131), and Ada came up with a hypothesis to predict the relation between water quality and population (Turn 132). Then Brad suggested to do an experiment saying "Try it" (Turn 134). Through the observation, Siddarth concluded that increasing filter flow made the water clean and it killed all the organisms in the tank (Turn 138). Based on this example, the students presented a lot of problematic propositions. However, they were operating in the way that scientists normally do. First propose problematic hypotheses, then conduct an experiment to test them, and finally draw a conclusion that might still be problematic. An important finding from recent work is that students with more sophisticated epistemologies seem to take better advantage of inquiry-based learning opportunities (Windschitl & Andre, 1998). As theory theorists assume that even young children have their own theories to explain the world, it is important to acknowledge the capability of young students to learn science. Therefore, although the reasoning was not perfect and lacked coherence here, the group in the example did exhibit a tendency toward using scientific way of thinking as well as using distributed cognition to co-construct conceptual understanding of the materials presented in the simulation model.

The frequencies suggest that all four groups spent large amounts of time and effort exchanging knowledge with each other. This points out the essence of collaborative learning as a process of sharing cognition. Yet, the low-achievement groups tended to be more engaged in knowledge exchange when exploring the simulation models than the high-achievement groups. Despite the importance of sharing knowledge among peers, to develop scientific understanding of the world, it is extremely important to provide students with sufficient opportunities and experiences to develop theories to explain the scientific phenomena. Sometimes, students tend to accept others' ideas without questioning and reasoning. The following excerpt from Group 14 illustrates one typical example.

138. Robby:	What did you put so far?
139. Jean:	The fish urine brings ammonia, the ammonia urine.
140. Robby:	Wait, the fish water bring ammonia
141. Jean:	No, the fish urine.
142. Robby:	Yea, the fish urine I meant. Yeah
……	
213. Robby:	How everything reacts in the tank.
214. Jean:	How all the acids and the fish react in the tank
215. Robby:	I just put how the acids and the fish react.

The above conversation was typical in many groups in Ms. W's classes since they were required to answer all the questions on the worksheet. It is easy to tell that the goal of Robby and Jean was to give a reasonable answer to the question. They were sharing answers without reasoning as they mechanically copied each other's ideas unproblematically. This further corroborates that the practice of knowledge exchange is not sufficient at all to foster collaborative scientific conceptual change. It is essential to involve other epistemic practices such as hypothesis testing, debate and argumentation, to occur in situated and collaborative contexts.

Comparing and Interpreting CORDTRA Representations

Reading CORDTRA Representations

CORDTRA representations were created to help visualize and compare the characteristics of group discourse and epistemic practices among across four groups. Figure 8, 9, 10, and 11 present the diagrams for the coded transcripts of Group 8 (high-achievement group from Mr. K's classes), Group 10 (low-achievement group from Mr. K's classes), Group 19 (high-achievement group from Ms. W's classes), and Group 14 (low-achievement group from Ms. W's classes) respectively and reflect the four days' group activities that the groups were working on the simulation models.

To read the diagrams, the numbers along the *x*-axis refer to the line number of each conversational turn. Along the *y*-axis are the numbers that represent each coding categories (for collaborative discourse coding and epistemic practice coding) and corresponding speakers. The different colors of symbols represents specific features as labeled in the legend on the right side in the diagram. Vertically, from bottom to top, the sequence of lines represent students' collaborative discourse coding categories (e.g., fact question, explanation question, confirmation question, agree, disagree, share, describe observation, retrieve prior knowledge, generate theory, paraphrase, warrant claim, identify cognitive conflict, plan, monitor, review, evaluate), facilitating categories (e.g., educational statement, performance statement, open questions, closed questions), epistemic practice coding categories (e.g., basic knowledge construction, observe, predict, design experiment, check knowledge validity, coordinate theory-evidence, modify knowledge, exchange knowledge), speakers and conceptual understanding levels. Therefore, the entries in the diagram refer to instances of discourse and epistemic practices as well as speakers indicated by the coding category on the *y*-axis at the turn indicated by the position along the *x*-axis.

For example, in figure 8, lines 1-17 refer to the codes for students' collaborative discourse. Lines 18-21 refer to the roles of facilitators when scaffolding Group 8's collaborative activities. Lines 22-30 refer to the epistemic practices that students operated during the collaborative exploration of the simulation models. Lines 31-35, identify the speakers including the facilitator and all the participating students in Group 8. The last four lines display the group conceptual understanding levels on various topics. The horizontal lines show the distribution of characteristics of students' discourse and epistemic practices, facilitator's roles, and how participants in the group took turns to contribute to the knowledge co-construction. In addition, the vertical view of the diagram helps match the characteristics of discourse with the features of epistemic practice at a certain point of conversational turn. Likewise, the same tactics apply to analyze the other diagrams. Several identical and different traits emerged through interpreting and comparing the CORDTRA representations across the four groups.

Similarities across Groups

The CORDTRA analyses found at least two common features across the four groups. One was that the simulation tools were frequently used throughout all the groups' activities. It is easy to see that the density of the tool related categories such as describing observation (in students' discourse) and observe (in students' epistemic practice was one of the highest among the coding categories even in the two low-achievement groups. In addition, the representation of group participation on the top of the CORDTRA diagrams demonstrated that in all groups, every participant was engaged in the group activity even though there were variances among the contribution. For example, in Group 8 (see figure 7), students 1 and 2 seemed to dominate the group conversation. Through CORDTRA, we could also tell the changes in the group structure. For example, in Group 8, student 4 seemed to be new to the group and only participated the last day's exploration with this group. In Group 10, student 5 only joined in this group for one class when student 1 was absent. For Group 19, CORDTRA representation also showed the group participants' variation in the four days' activities, that is student 4 and 5 didn't join this group until the last day's activity. In Group 14, student 4 and 5 joined the group activity on the second day when student 1 and 2 were absent. The variation in group participation was caused by several possible reasons, such as certain student's absence from classes, school event, or teacher's regrouping of the students to balance the group size in the class.

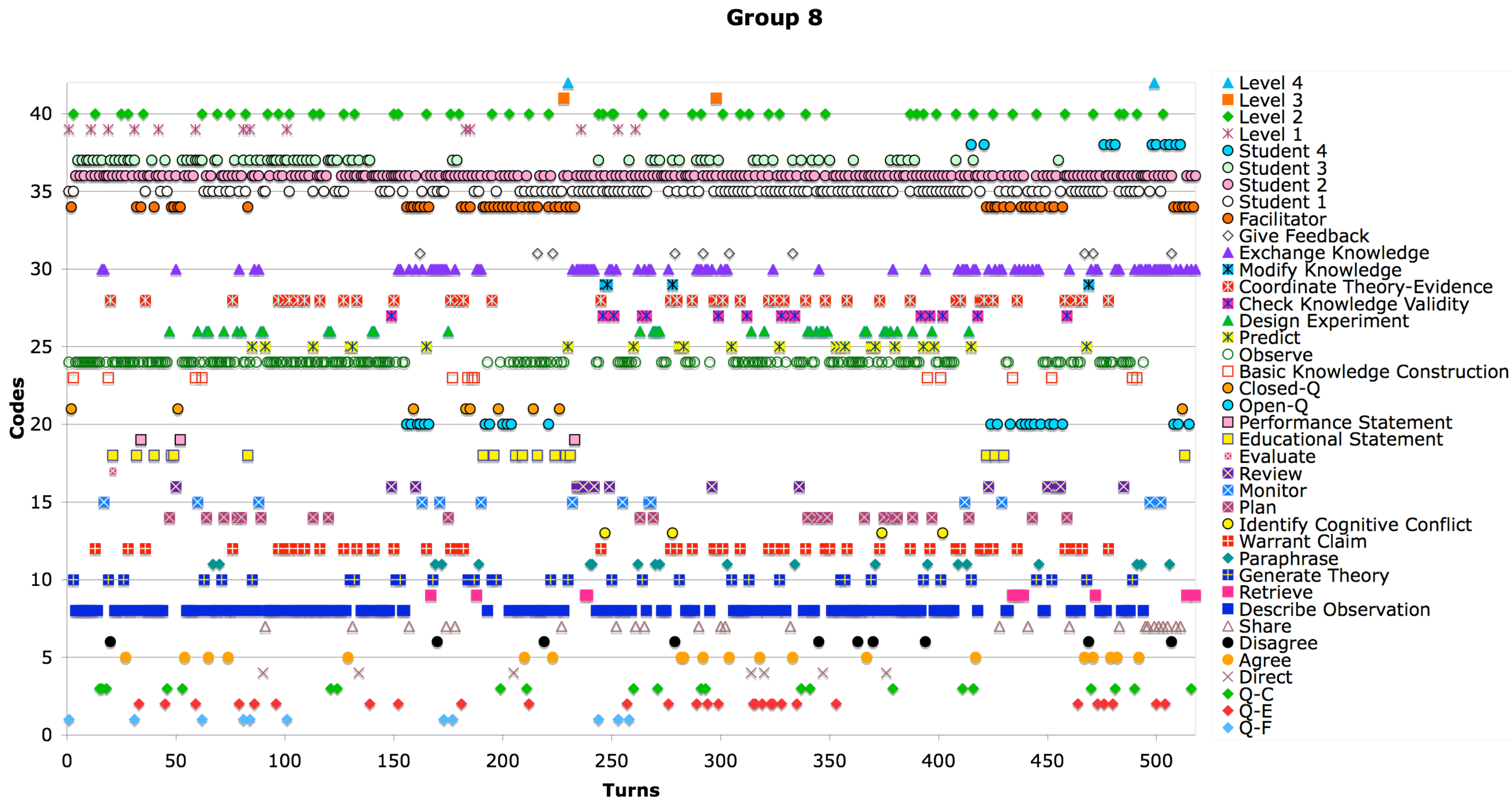

Figure 8. CORDTRA Diagram for Group 8 (High-achievement group from Mr. K’s Classes)

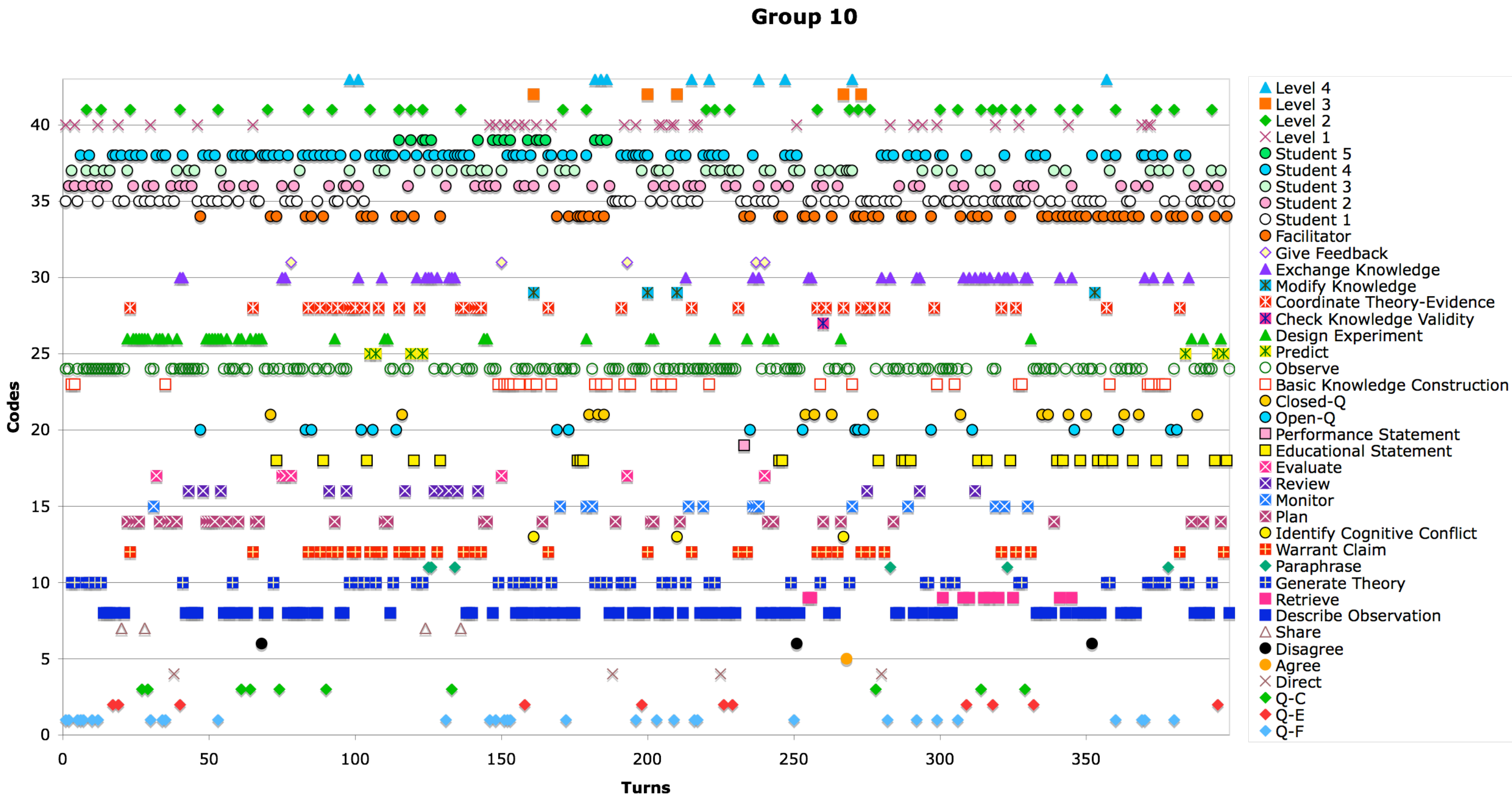

Figure 9. CORDTRA representation for Group 10 (Low-achievement Group from Mr. K’s Classes).

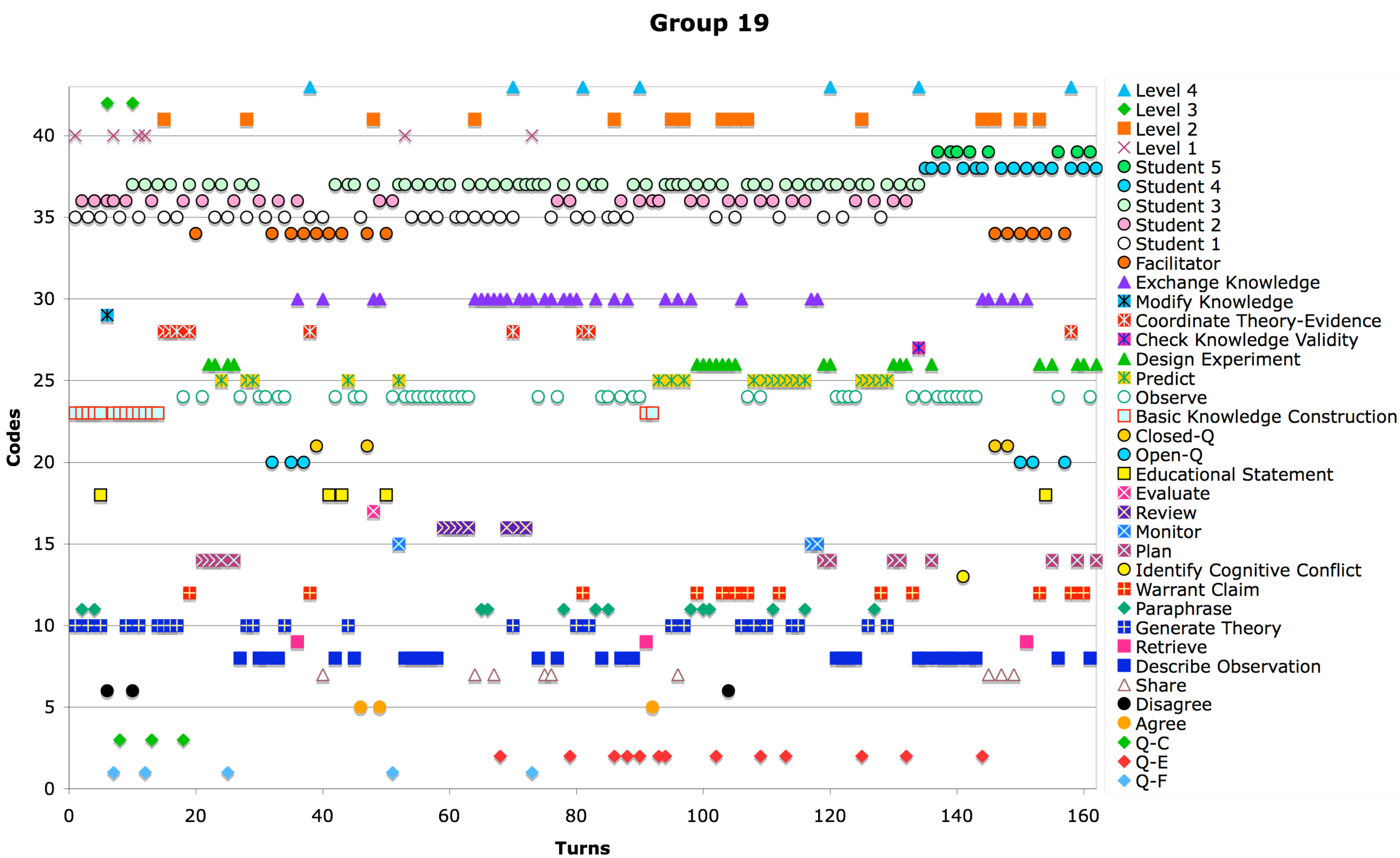

Figure 10. CORDTRA representation for Group 19 (High-achievement group from Ms. W’s Classes).

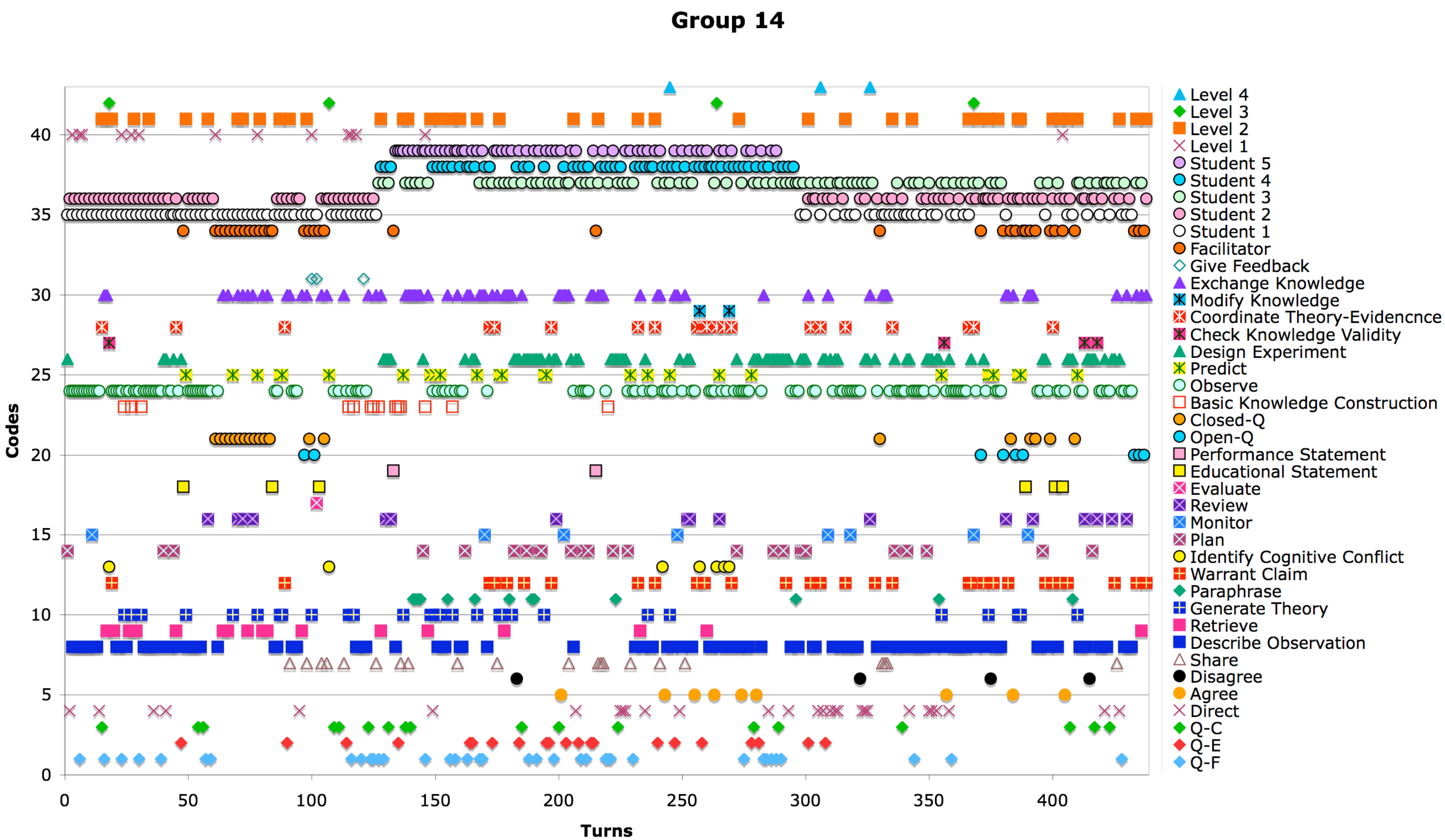

Figure 11. CORDTRA representation for Group 14 (Low-achievement Group from Ms. W's Classes).

The common features discovered in the CORDTRA representations indicated that all the groups were fairly engaged in the simulation-based learning despite the variation of group structure. Furthermore, students' frequent use of simulation models indicated the computer tools served as a medium to stimulate group discussion and develop scientific epistemic practices to conduct experiment. As shown in the CORDTRA representations, students were generating theories and warranted claims along their observing activity. In addition, there was some association between the conceptual understanding level and the types of questions the students proposed. Particularly at the examined level (level 4) of understanding which is the highest level, the students showed a tendency toward asking explanation questions. However, the groups showed differences in how they used and interpreted the simulation models. For example, there seemed to be cycles of sharing, generating theory, generating warranted claims that continued through the simulations in Group 8 and Group 19 (the high-achievement groups). However, such cycles dropped out later in the other two low-achievement groups.

Relations between Collaborative Discourse and Epistemic Practice

The vertical view of the CORDTRA representation helps match the discourse with the epistemic practices at a certain point of conversational turn. Previous results showed the importance of the feature of warranted claims in student discourse, it would be interesting to see what epistemic practices were employed on and around the conversational turns when warranted claims were generated. Therefore, the following CORDTRA analyses focused on the conversational turns where warranted claims occurred in group discourse.

The two groups from Mr. K's classes (Group 8 and 10 in Figures 7 and 8) produced several number of warranted claims in a row along with the following epistemic practices: observe, predict, coordinate theory-evidence. For example, in group 8 (see figure 7), turns 97-116 were where several sentences of warranted claims occurred. Students were engaged in three types of practices: coordinating theory-evidence, observing, and predicting as shown in the following excerpt form group 8.

97. Brad:	Why? Why is it like that?
98. Ada:	The water quality is no good.
99. Brad:	Oh no, the number of population.
100. Ada:	I think.. The water quality.
101. Brad:	cause as the burst of the population, the water quality goes down and because of it. The death increases so that makes the water quality go up again. So that will just keep happening gradually. See, it happens again… Except it went down even farther (inaudible).
102. Brad:	What stands for the p spawn?
103. Siddarth:	But lots of them are dying cause there isn't enough food.
104. Ada:	Look at the number spawn.
105. Brad:	Some of them are dying.
106. Ada:	But lots of them, most of them are dying.
107. Brad:	Cause there is no food.
108. Ada:	Oh my god, they are just eating the baby ones.

109. Brad: They are actually lucky if they survive, and actually get bigger.

110. Ada: Because every time they reproduce.

111. Brad: Look at the population

112. Ada: Old age, 55.

113. Brad: Two hundreds.

114. Siddarth: And if you increase it to 2000 they'll die more quicker.

115. Brad: It's dropping.

116. Ada: Poor water death.

117. Ada: Cause there is no food.

From this excerpt, we can see that, in Turn 98, Ada brought up the causal relation between water quality and the decrease in fish population in the fish tank. Brad coordinated this theory using his prior knowledge and the observation in the simulation model in Turn 101. Then Siddarth presented an alternative explanation that it might be lack of food that caused the drop of population (Turn 103). To test the validity of Siddarth's warrant, the group went on to observe what occurred in the model. During the observation, Siddarth made a prediction in Turn 114, that "if you increase it (population) to 2000 they will die more quicker." The observation supported Siddarth's prediction. Ada agreed with Siddarth's argument that population might drop because of lack of food (Turn 117). These combinations of epistemic practices helped the group to generate, warrant, and test alternative claims, thus they co-constructed a more comprehensive understanding.

Both groups from Ms. W's classes (Group 14 and19) tended to generate warranted claims when they were designing experiments and observing. Surprisingly, coordinating theory-evidence was not associated with warranted claims very often. To illustrate, turns 172-186 of Group 14 are presented in the following excerpt.

172. Judy:	Yeah, because it's going to eat it up.
173. Robby:	And for decrease..
174. Jean:	More, because it's not going to have enough things to eat it up.
175. Jean:	I know which one does the nitrite go down as the level, but then do the…
176. Robby:	But then the nitrite gives off oxygen for the fish
177. Jean:	So the fish would like grow more
178. Bobby:	Breathe. You die if you stop breathing.
179. Jean:	Yea so they would like live
180. Robby:	Yea as the fish live…
181. Jean:	The plants…will also give off
182. Robby:	What would I changed? I'd change the number of plants right? Wait, what would I change? The number of plants because we were told…
183. Judy:	No, because we have to increase it.
184. Jean:	We have to change the plants because why?
185. Robby:	What did you put for the why?

186. Judy: I will do that because I have to increase the number of plants to see what happens

Along with the above conversation, Group 14 was trying to answer a question on the worksheet that asked what variable they wanted to change and why. This excerpt represented typical conversations in Ms. W's classes when the groups were working on the worksheet while exploring the models. Both Judy and Robby were contributing to answering the question on the worksheet. Jean seemed to take the role as coordinator and recorded their answers. However, for some reason, the following up or adding to each other's ideas was missing in this conversation. Instead, it seemed the goal of the conversation was to get the question answered with any answer they could come up with. This resulted in the lack of coherence between students' warranted claims and coordinating theory-evidence. In other words, the warranted claims were not to support the previously proposed theories. This constrained the reasoning of students. Instead of using the simulation models as a tool to improve understanding, the task of exploring models became the learning target of the group. For example, on line 186, Judy explained "why she increase the number of plant" was because she "has to increase to see what happens." This showed a disconnection between the warranted claims and theories.

Summary of CORDTRA Analyses

In sum, similarities and differences occurred in the groups' CORDTRA diagrams. The common features discovered in the CORDTRA representations indicated that all the groups were fairly engaged in the simulation-based learning despite the variation of group structure. Furthermore, students' frequent use of simulation models indicated the computer tools served as a medium to stimulate group discussion and develop scientific epistemic practices to conduct experiment. However, the groups showed great differences in how they interpreted the simulation tools during their exploration.

The differences demonstrate discrepancies in interpreting the simulation tools. The two groups from Mr. K's classes used the computer tools as a medium to share knowledge and build on and integrate each other's ideas. In contrast, the groups from Ms. W's classes regard the simulation tools as the learning goal for student learning. To be specific, she stressed the importance of understanding the representations shown in the simulations but failed to use the simulations as a tool o help understanding the abstract system knowledge. This might have been constrained by the design of the worksheets.

Sequential Analysis

Sequential analyses were conducted in MEPA program (Erkens, 2005), which also helped generate the frequency and mean percentage analyses for the discourse and epistemic practices codes. The visual transition diagrams were created with significant transitional events linked to show the relations between characteristics within the dimension of collaborative discourse or epistemic practices. The transition diagrams result from sequential analyses with the thickness of the links indicating the level of significance. The arrows represent the sequences in the transition relations between two variables. In the diagrams created in MEPA program, if there is no arrow between two variables, it refers there is no significant relations between them. The circle with an arrow around one certain variable represent that the next possible sequence is the variable itself.

Considering the power of the sequential analyses, only eight coding categories where group differences occurred in previous analyses were selected for two-code sequential analyses that only calculate the *transitional probabilities* between every two sequential codes. The selected categories include fact questions (Q-F), explanation questions (Q-E), describe observations, generate theory, paraphrase, warrant claim, identify cognitive conflict, and plan. These categories were selected because these were where the group difference lied in according to the frequency comparisons. Table 11 summarizes all the significant transitions. Figure 12 shows an example transition diagram for group 14's collaborative discourse. It is necessary to note that all the arrows displayed in the maps only infer the relations between two codes and does not infer multiple sequential relations among multiple codes. For example, in figure 12, the arrows connecting "generating theory", "paraphrasing", and "explanation question" only infer that there were significant transitional relations between "generating theory" and "paraphrasing", "paraphrasing" and "explanation question", "explanation question" and "generating theory". In addition, only the arrows can infer the sequential relations and the lines cannot. As shown in figure 12, even though the line goes through "paraphrasing" and "plan", there is no significant transitional relation between these two variables because there is no arrow connecting them.

Transition Patterns of Collaborative Discourse

Comparing the four transition diagrams of collaborative discourse shows one typical pattern across all four groups is that students tend to continue to describe observations in several sequences, consistent with previous findings that students tended to spend a lot of time on describing observations. Another interesting finding is that warranted claims seem to be the discourse characteristic that lead to other cognitive processes. For example, in Group 8's transcripts, students tended to identify cognitive conflict after generating a warranted claim. This indicates that warranted claims may be an essential factor to elicit student reflection thus help realize the gap between alternative ideas. In Group 19, warranted claims were frequently followed by paraphrasing. Possibly, students tended to clarify ideas when warranted claims were present. In addition to warranted claims, explanation questions were also a frequent characteristic in the significant transitions. For example, it led to paraphrasing in both Group 10 and Group 19, and was followed by generating theory in Group 14. However, no apparent discourse patterns differences were observed between high-achievement and low-achievement groups.

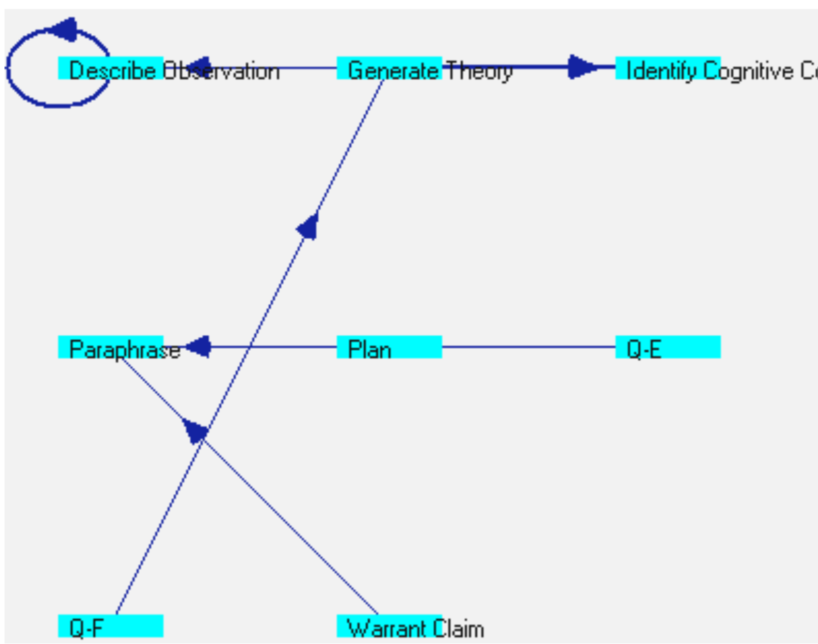

Figure 12. Transition Diagram for Group 14's Collaborative Discourse Characteristics.

Table 11. Summary of Significant Sequential Transitions in Four Groups.

Group	Collaborative Discourse	Epistemic Practice
8	Describe Observation → Describe Observation Paraphrase → Paraphrase Generate Theory → Paraphrase Warrant Claim → Identify Cognitive Conflict	Basic Knowledge Construction → Basic Knowledge Construction Observe → Observe Knowledge Exchange → Knowledge Exchange Modify Knowledge → Modify Knowledge Basic Knowledge Construction → Check Knowledge Validity Check Knowledge Validity → Modify Knowledge Predict → Knowledge Exchange
10	Describe Observation → Describe Observation Generate Theory → Generate Theory Paraphrase → Paraphrase Plan → Plan Q-F → Q-F Warrant Claim → Warrant Claim Identify Cognitive Conflict → Generate Theory Q-E → Paraphrase	Basic Knowledge Construction → Basic Knowledge Construction Design Experiment → Design Experiment Observe → Observe Basic Knowledge Construction → Check Knowledge Validity Check Knowledge Validity → Coordinate Theory-Evidence Knowledge Exchange → Coordinate Theory-Evidence Coordinate Theory-Evidence → Predict Predict → Knowledge Exchange
19	Describe Observation → Describe Observation Generate Theory → Describe Observation Generate Theory → Identify Cognitive Conflict Q-E → Paraphrase Warrant Claim → Paraphrase	Basic Knowledge Construction → Basic Knowledge Construction Coordinate Theory-Evidence → Coordinate Theory-Evidence Design Experiment → Design Experiment Knowledge Exchange → Knowledge Exchange Observe → Observe Predict → Predict
14	Describe Observation → Describe Observation Plan → Plan Generate Theory → Paraphrase Generate Theory → Q-F Paraphrase → Q-E Q-E → Generate Theory	Basic Knowledge Construction → Basic Knowledge Construction Design Experiment → Design Experiment Knowledge Exchange → Knowledge Exchange Observe → Design Experiment Predict → Predict Design Experiment → Predict Predict → Check Validity

Transition Patterns of the Epistemic Practice Features

As to the patterns of the epistemic practice features, students tended to repeat one particular practice frequently in a group, such as basic knowledge construction, knowledge exchange, design experiment. One possible explanation is the peer influence. That is, students tend to follow the practice that their group peers execute in their learning. It is interesting to see other patterns involving combined scientific practices, such as Check Knowledge Validity → Coordinate Theory-Evidence, Coordinate Theory-Evidence → Predict, Design Experiment → Predict, Predict → Check Validity. This is interesting because scientists frequently use such patterns when they explore the world. This further indicates that young may be engaging in scientific ways of thinking. Although there are obvious group diversities in terms of the emerging transition patterns, it is not clear how the high-achievement groups differ from the low-achievement ones.

Trajectories of Conceptual Change

To make connections among the discourse, epistemic practices, and conceptual understanding, probability cross tabulations were created using MEPA software to examine the trajectories of conceptual change, specifically extending to what types of discourse or epistemic practices are more likely to occur at each level of conceptual understanding. For all the four cases, only the turns on the topic of Nitrogen Cycle were selected for this analysis because of its key role in understanding the aquarium ecosystem. The probability for each code in the collaborative discourse and epistemic practices was calculated using the conceptual understanding level as the episode filter which was used to separate series of turns with specific conceptual understanding characteristics. Table 12 displays the probability cross tabs of discourse codes and conceptual understanding levels, and table 13 displays the cross tabs of epistemic practices and conceptual understanding levels.

Table 12. Cross Tabs for Collaborative Discourse and Conceptual Understanding.

	Level 1 Recognizing Level	Level 2 Explanatory Level	Level 3 Critiquing Level	Level 4 Examined Level
Fact Question	3.06%	1.41%	0.24%	0.00%
Explanation Question	1.18%	4.00%	0.24%	0.47%
Confirm Question	2.12%	3.06%	0.00%	0.00%
Directing Statement	0.24%	0.71%	0.00%	0.00%
Agree	0.24%	2.35%	0.24%	0.24%
Disagree	0.00%	0.94%	0.00%	0.24%
Share Knowledge	0.71%	3.06%	0.00%	1.65%
Describe Observation	8.47%	14.59%	1.18%	3.06%
Retrieve Prior Knowledge	1.18%	1.65%	0.00%	0.00%
Generate Theory	5.41%	5.88%	0.24%	0.94%
Paraphrase	0.94%	3.53%	0.00%	0.71%
Warranting claim	0.24%	6.59%	0.47%	0.47%
Identify Cognitive Conflict	0.24%	0.47%	1.41%	0.00%
Plan	0.47%	2.35%	0.47%	0.71%
Monitor	0.94%	1.65%	0.24%	0.94%
Review	0.47%	0.94%	0.00%	1.65%
Evaluate	0.24%	0.24%	0.00%	0.00%
Educational Statement	0.47%	1.18%	0.00%	0.47%
Open Question	0.24%	0.71%	0.00%	0.00%
Closed Questions	0.24%	0.47%	0.00%	0.24%
Miscellaneous	0.24%	0.47%	0.00%	0.00%
Total	27.29%	56.24%	4.71%	11.76%

Table 13. Cross Tabs for Epistemic Practices and Conceptual Understanding.

	Level 1 Recognizing Level	Level 2 Explanatory Level	Level 3 Critiquing Level	Level 4 Examined Level
Basic Knowledge Construction	7.53%	0.47%	0.47%	0.00%
Observe	12.24%	21.65%	1.88%	4.94%
Predict	0.24%	4.00%	0.00%	0.71%
Design Experiment	0.47%	3.76%	0.47%	0.47%
Coordinate Theory-Evidence	0.47%	6.12%	0.24%	0.94%
Check Validity	0.00%	0.94%	0.24%	0.24%
Modify Knowledge	0.00%	0.00%	0.71%	0.00%
Knowledge Exchange	4.94%	14.59%	0.47%	3.53%
Give Feedback	0.24%	1.18%	0.00%	0.24%
Scaffold	0.94%	2.35%	0.00%	0.71%
Miscellaneous	0.24%	0.47%	0.00%	0.00%
Total	27.29%	56.24%	4.71%	11.76%

The totals in the probability tables show how the groups discuss the Nitrogen Cycle. The data showed that 56.24% of their discussion mostly stayed at the explanatory level (level 2) in which they generated causal reasoning. The critiquing level (level 3, 4.71%) rarely occurred in the group discussion. At the recognizing level (level 1), students mostly focused on describing observation (14.59%) and generating theories (5.88%). Accordingly, they were using practices like basic knowledge construction (7.53%), observation (12.24%), and exchanging knowledge (4.94%). At the explanatory level (level 2), generating warranted claims (6.59%) and explanation questions (4.00%)

became one of the major features of students' discourse. At this point, the groups increased the frequency of knowledge exchange (14.59%) among group members. In addition, coordinating theory-evidence (6.12%) was frequently used. At the critiquing level (level 3), students focused on pointing out the cognitive conflict (1.41%) during the practice of observing simulation activities (1.88%). It is interesting to note that students only asked fact questions at the lower levels of conceptual understanding. In addition, when reaching the examined level (level 4), the major features of the group discourse were describing observation, sharing and reviewing knowledge. These results indicate that students started their conceptual understanding with describing observations and generated hypotheses. With the development of conceptual understanding, they moved on to generate warranted claims applying the practice of coordinating theory-evidence, during which process they frequently asked explanation questions and exchanged ideas. When they reached the highest level of understanding (i.e., the examined level, level 4), they used observations as data to support their theories. Therefore, there seemed to be a cycle of observing, generating hypotheses, explaining observed phenomena, and testing hypotheses and validity of theories.

Qualitative Examples

Sequential analyses found many transition patterns in students' collaborative discourse and epistemic practice. Some of these patterns involve key features that are important for students to develop conceptual understanding, such as warranted claims, coordinating theory-evidence, predicting, designing experiment, and checking knowledge validity. In this section, I present examples from group transcripts to illustrate the patterns in students' discourse and epistemic practices and discuss how these patterns contribute to student conceptual change. One excerpt was selected from every group to present how groups developed understanding of the Nitrogen Cycle concept.

Transcript Excerpt from Group 8 (Turns 241-252). The following excerpt reveals how students in Group 8 (the high achievement group from Mr. K's classes) used the computer simulations to construct conceptual understanding on the concept of Nitrogen Cycle.

241. Siddarth:	There is one white and purple.
242. Ada:	See the red is ammonia, and white is…hold on.
243. Siddarth:	And that is purple. Slow it down.
244. Brad:	What is that?
245. Ada:	We think they are bacteria, cause they are like…look it when the dots go…they are been…
246. Siddarth:	The blue thing changes the yellow in the white.
247. Ada:	I thought was red to white
248. Siddarth:	Red to white, yeah. And the purple thing changes red to yellow.
249. Siddarth:	What is the red one? Oh, oh, the red one is ammonia So white one is…
250. Ada:	I guest this is what a filter for
251. Siddarth:	Makes to white. The blue thing makes red to white, and then purple thing makes it.

252. Ada: Red, white, red and blue, get it? Hey does the nitrogen cycle do something like that. What'd happen if we change the water? Oh, that is so cool.

This conversation demonstrates quality in both collaborative discourse and epistemic practices. From the beginning of the dialogue, both Ada and Siddarth were describing their observations (Turns 241 and 242). That is, they were conducting the epistemic practice of observation in the computer-supported environment. Brad initiated the question "what is that (the purple patch in the model)?" in Turn 244, which elicited the entire conversation on bacteria. Most interestingly, this dialogue showed how Ada and Siddarth collaborated together to present evidence for the prediction that the purple patches represent bacteria in the model. At first Siddarth shared his observation as evidence that "The blue thing changes the yellow in the white." Then Ada presented an alternative view that "I thought was red to white" (Turn 246). At this moment, both Adaa and Siddarth were not positive whose knowledge was correct. Such uncertainty led the group to use the computer tool to test ideas and check knowledge validity. At the same time, Siddarth exchanged prior knowledge about the red dot representation in the model (Turn 249). Based on Siddarth's input, in Turn 250, Ada made another prediction that the white dot had the function as the filter. This prediction made the following observation productive and Siddarth finally successfully figured out the pattern occurred in the model that the blue patch converted the red dots into white and then the purple patch converted the white into yellow. This discovered patterned triggered Ada to retrieve the prior knowledge on Nitrogen Cycle, and she was excited that it made sense by saying "oh, this is so cool."

This excerpt demonstrated that the students went through several sequential patterns involving epistemic practices, such as from predicting to observing, then from observing to check knowledge validity. The conversation also showed some high quality patterns of discussion such as using observed phenomena as evidence to support one proposition. These patterns of the collaborative discourse and the epistemic practices aroused the change in student conceptual understanding from recognition level (uncertain about what the purple was) to an explanatory level (level 2) (explaining observed phenomena with retrieved prior knowledge). Therefore this example indicates that patterns of collaborative discourse and epistemic practice that include beneficial characteristics may have positive effects on students' collaborative conceptual understanding.

Transcript Excerpt from Group 10 (Turns 247-259). The next excerpt reveals how students in Group 10 (one low-achievement group from Mr. K's classes) explored the Nitrogen Cycle model differently.

247. Robert:	The ammonia is peaking…
248. Julie:	There is 49 ammonia. Obviously it is the red
249. Robert:	Now maybe the blue is fish see look 1, 2, 3, 4, 5, 6. Okay it can't be
250. Allison:	Yeah but then what is the purple that is taking over this
251. Robert:	It's not taking over
252. Allison:	It goes on to the blue
253. Chelsea:	I had function of a fish and plants and algae
254. Chelsea:	No but she has bacteria, snails

255. Julie:	I think the blue is…I don't think it is snails cause it wouldn't be eating the ammonia
256. Allison:	Maybe the white is snails
257. Julie:	Hold down, let me try this again
258. Chelsea:	It wouldn't be bacteria because the bacteria eats the ammonia and it is not doing that
259. Allison:	What is that? There are 10 fish but there are only 6 on the screen

Compared to Group 8, Group 10 used some similar strategies to construct knowledge, such as using the simulation models to test hypotheses. When Robert generated a hypothesis that "the blue is fish" in Turn 249, he counted the number of the blue patches on the screen and then rejected this theory since the number did not match the number of fish (which was shown in the counter). This is a good example of how students used the model to collect evidence and coordinate theory and evidence. The group moved on to the next question "what is the purple?" Then Chelsea started comparing her notes to other group member's, saying "But I had the function of a fish and plants and algae. No but she has bacteria, snails" in Turns 253 and 254, to provide clue for the group's meaning making. Julie proposed another warranted claims to dispute the hypothesis that the blue is snails "cause it wouldn't be eating the ammonia" (Turn 255). Then Julie proposed another hypothesis that "maybe the white is snails" in Turn 256. When Julie was to make an observation in the model, Chelsea asserted that "It (not clear what she referred to here) wouldn't be bacteria because the bacteria eats the ammonia and it is not doing that." (Turn 258)

At first glance, it seemed it was a good conversation since students presented several warranted claims. Several sequential patterns emerged in the excerpt as well, such as moving from describing observation to generating warranted claims, following observing with coordinating theory and evidence. On closer examination, the problem is that this talk is not a two-way conversation. Instead, most of the time, the students in this group were talking in parallel. They were neither assimilating nor accommodating the information from peers because they neither absorbed or integrated each other's ideas. Therefore, there was some dissonance in the talk that hindered the continuous development of ideas. This excerpt indicated that the intra-group communication is needed to benefit collaborative activities.

Transcript Excerpt from Group 19 (Turns 62-72). The third example reveals how students in Group 19 (the high-achievement group from Ms. W's classes) engaged in meaning making regarding Nitrogen Cycle model.

62. Kyle: Well what do we see? A whole bunch of colors. Yeah a whole bunch of dots.

63. Charlie: How does this relate to what you saw in the aquarium?

64. Connor: maybe the ammonia was…

65. Charlie: yeah it relates with the increase in the ammonia and um. With the increases and the decreases of the…nitrogen.

66. Connor: the increase and decrease of what?

67. Surbha: you know the first that increases is ammonia

68. Connor: The blue bacteria decreases the ammonia

69. Surbha: what is the different kinds of things the model?

70. Connor: Death.

71. Surbha: That doesn't make sense.

72. Charlie: This question doesn't make sense.

The dialogue showed how students in Group 19 reasoned in Ms. W's classes where they were required to answer the questions on a worksheet. When Kyle started describing his observation, Charlie led the group to think how to answer one of the questions on the worksheet: "How does this relate to what you saw in the aquarium?" (Turn 63). Then Connor retrieved the knowledge about ammonia (Turn 64), and Charlie built on this piece of information to make connections between the observed phenomena and retrieved prior knowledge on Nitrogen Cycle, stating "it (observation) relates with the increase in the ammonia and um. With the increases and the decreases of the…nitrogen." (Turn 65). With Connor's request for knowledge clarification (Turn 66), Surbha reiterated the idea of Charlie's by saying "you know the first that increases is ammonia" (Turn 67). Then Connor followed Surbha's clarification with a hypothetical theory that "The blue bacteria decreases the ammonia" (Turn 68) to explain what happened in the model. Then the group turned to another question on the worksheet: "what is the different kinds of things the model?" Connor believed death was one of the observed things (Turn 70). Then Surbha gave a feedback with "this does not make sense" (Turn 71), and Charlie critiqued the question (Turn 72).

As shown in this example, Group 19 successfully assimilated the observed phenomena occurred in the computer simulations with what they had learned before. This group used the computer tools differently from the previous two groups from Mr. K's classes. The previous examples showed that for Groups 8 and 10, the computer simulations served as a facilitating tool for collaborative reasoning and knowledge construction as well as a context to test hypotheses and predictions. In contrast, to Group 19, the simulation tools were used as a tool to activate prior knowledge with limited depth of reasoning due to the constraints placed by the worksheet task. The difference in interpreting the function of simulation tools led to different discourse and epistemic practice strategies. As demonstrated in this example, several sequential patterns occurred. For example students' observing was followed by generating a prediction, and the practice of coordinating theory-evidence followed with observing. At the end of the dialogue, Group 19 also successfully improved their conceptual understanding level from initial recognition level to the explanatory level (level 2).

Transcript Excerpt from Group 14 (Turns 1-17). This last example excerpt reveals how students in Group 14 (the low-achievement group from Ms. W's classes) operated the Nitrogen Cycle simulation model.

1. Chris:	Get more plants. let's do 10 and 10 and see what happens
2. Gabby:	We have put, no you have to press set up, cause she said every time..
3. Chris:	Okay now is just all ammonia is anyone?
4. Gabby:	See at least is going up, 129
5. Chris:	Now there is low 50, now there is little nitrite
6. Gabby:	Wait where is the nitrite, I don't see any nitrite
7. Chris:	The yellow, oh (pointing at the graph)
8. Gabby:	Oh I see it, it's at zero
9. Chris:	But the nitrite is like two. Oh!

10. Gabby: Now it says change the water

11. Chris: I didn't know you were supposed to change the water

12. Gabby: Okay so the big blue blocks

13. Chris: Ammonia is too high, now, okay change water change water

14. Gabby: No no change the water

15. Chris: Does it help?

16. Gabby: What she said nitrite was again? Nitrate?

17. Chris: Ammonia turns into nitrate and nitrate turns into nitrite, and plants eat the nitrite

The group discourse showed that this group of students did a lot of manipulating operations with the simulation model, such as changing the values of variables and clicking the change water button. One typical pattern emerged in this example is that they were constantly repeating the epistemic practice of observation. Therefore the major discourse characteristic here is to describe what happened in the model. Even though at the end Chris retrieved the knowledge about Nitrogen Cycle (Turn 17), it was not clear whether it could be contributed to the group process. Most likely, Gabby just recalled Ms. W's previous instruction on Nitrogen Cycle. This example demonstrates a less productive collaborative discourse with insufficient cognitive reasoning.

To summarize, the above four examples of different groups' conversation showed great variability in students' collaborative discourse and epistemic practices, even though all the four groups did improve their conceptual understanding level from recognition level to the explanatory level (level 2). Both groups from Mr. K's classes (Group 8 and

Group 10) showed significant patterns involving high quality discourse characteristics (e.g., warranted claims) and scientific epistemic practices (e.g., predicting, observing, and coordinating theory-evidence). However, Group 8 and 10 differed in how the group members interacted with each other and how they built on each other's ideas. Group 8 showed more integration of group knowledge than Group 10. This explains why Group 8 was successful because cognitive processes such as operating on the ideas of one's partners promote cognitive advances (Kruger, 1992). The other two groups from Ms. W's classes (Group 19 and Group 14) exhibited similarities in retrieving prior knowledge to explain the simulation model, however, to different extents. The high-achievement group (Group 19) displayed more sophisticated epistemic practices than the low-achievement group who only emphasized the practice of observation. Finally, it appears there are differences among the groups across the two classroom settings concerning how they use the simulation tools. Specifically, the groups from Mr. K's classes considered the simulation tools as a facilitating medium to initiate and test ideas, and to not only assimilate with existing knowledge but also to construct new knowledge. Nevertheless, the groups from Ms. W's classes used the simulation tools to activate prior knowledge and assimilate knowledge.

CHAPTER 6

GENERAL DISCUSSION

The goal of this study was to examine students' collaborative scientific conceptual change process while using computer simulations to understand aquarium ecosystem through three perspectives (i.e., cognitive, social, and epistemic). To reach this goal, a mixed quantitative and qualitative analysis method was applied to investigate both students' conceptual understanding achievement (conceptual change) and their group interaction including collaborative discourse and epistemic practices that led to such achievement (trajectories of conceptual change). First, this chapter presents the summary of the main results with a general discussion addressing the research questions. In addition, theoretical and pedagogical contributions are provided. Finally, limitations of the study will be addressed with suggestions for future studies.

Findings

The development of scientific knowledge involves "knowing" science (i.e., scientific conceptual understanding), "doing" science (i.e., scientific epistemic practice), and "talking" science (i.e., scientific discourse; Duschl & Gitomer, 1991; Lee & Luykx, 2006). This dissertation proposes a new model conceptual change to address all the three elements in learning science: collaborative discourse, epistemic practice, and collaborative scientific conceptual change. A classroom study was conducted and the data were analyzed using this new model to address the following four research questions:

1. What conceptions change occurs as a result of participating in a technology-enhanced curriculum unit for learning about aquarium ecosystem?
2. What collaborative discourse patterns emerge during the collaborative use of computer tools and how are they related to student conceptual change?
3. What epistemic practice patterns emerge during the collaborative use of computer tools and how are they related to student conceptual change?
4. What are the trajectories of collaborative scientific conceptual change?

What Changes in Conceptual Change?

The results of the pre-/posttests data analyses suggest that the RepTools simulations support student conceptual change, as shown by the significant gains particularly in the structural, behavioral and functional aspects of the system. These latter aspects of the system are implicit and difficult to learn, however critical for understanding science (Hmelo-Silver, Marathe, & Liu, 2006). Two factors contributed to students' achievement of conceptual change: simulation-based learning context and collaborative interactions.

The visualization and manipulative opportunities provided by simulation-based learning environment afford students an opportunity to test and refine their hypotheses. It was such affordances that made the behavioral and functional knowledge tangible and visible for students to construct deep understanding, which eventually led to both knowledge enrichment and revision. In addition, the results clearly show that the quality of students' collaborative discussion and practices does make a difference in students' understanding. Literature shows that the collaborative discussion around the use of simulation models helped students activate and restructure the existing knowledge distributed among the group (Roschelle, 1992). Simulations help students create shared meaning through external representations. These visual representations allow students to discuss the learning domain without ambiguity and confusion and to engage in epistemic practices needed to do science.

In addition to investigating students' achievement of conceptual change, this study used the collaborative scientific conceptual change model to examine students' trajectories of collaborative scientific conceptual change with a focus on investigating students' collaborative discourse and epistemic practices.

Computer-Mediated Collaborative Discourse

The findings from different data analyses in this study elucidate the importance of collaborative discourse in students' scientific conceptual change. One of the major results reveals that there is great variability in groups' discourse and warranted claims is a key feature to judge the quality of collaborative discourse and contribute to developing conceptual understanding. This result is consistent with a robust finding in educational research that giving explanations is beneficial for students (Webb, 1992). Generating warranted claims require students to be cognitively engaged in order to capture the cause-effect relation to provide adequate grounds for an argument or interpretive proposition. In collaborative learning, alternative warranted claims generated by different group members help to build on each other's ideas. Recent science reform emphasizes "talking science," whereby "teachers structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse. A fundamental aspect of a community of learners is communication" (NRC, 1996, p. 50). In addition to teacher facilitating, the results clearly show the mediating role of computer simulations as contributing a resource to promote collaborative discourse. In the simulation-based learning context, students frequently used the observed phenomena as supporting data to warrant claims. Roschelle and Teasley (1995) elucidated three possible mediating roles of computer simulations in his study: disambiguating language, actions with the mouse as alternative means for producing conversational turns, inviting and constraining interpretations by immediate display of testing results.

Simulation-Mediated Epistemic Practices

Epistemic practice features express the way that students come to know science through doing science, that is, engaging in science inquiry by designing and carrying out experiments to test hypotheses and coordinating theory and evidence to make sense of the world. Few students see science as a process of building and testing explanatory models and theories. Instead, they see science as an accumulation of facts about the world (Carey & Smith, 1993; Driver et al., 1996; Lederman, 1992; Linn & Songer, 1993). This hinders students' deep conceptual understanding of science knowledge. This study also investigated students' epistemic practices as they develop their conceptual understanding.

Consistent with the findings on collaborative discourse, there was variability in groups' in use of epistemic practices. The consistency between the findings from collaborative discourse and epistemic practices may result from the overlap among the categories in these two coding schemes.

The MLA analyses found that predicting and coordinating theory and evidence were key practices that predicted students' individual posttest performance. Scientific knowledge is comprised of theory and empirical evidence. It is crucial to interrelate these two pieces together to understand what science is and how it works (Kuhn & Pearsall, 2000). A wide range of research has demonstrated the critical role of explanations in supporting learning (Carey, 1985; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Gelman &Wellman, 1991; Gopnik & Meltzoff, 1997; Murphy, 2002). Coordinating theory and evidences produces explanations to integrate hypothesized theories and collected evidences from the simulating activities. Throughout the study, the students used computer simulations to mediate their epistemic practices. For example, they collected patterns of data through observing simulations, generated theories based on their observations, and constructed causal explanations to connect data with theories.

Trajectories of Collaborative Scientific Conceptual Change

Both students' collaborative discourse and epistemic practices contribute to their conceptual understanding. In addition, the results indicate that scientific epistemic practices go hand in hand with high-quality collaborative discourse to promote students' conceptual learning. The cross tabs from the sequential analyses found that the frequencies of explanation-related features in students' discourse and epistemic practices increases with the improvement of their conceptual understanding level of Nitrogen Cycle. The CORDTRA diagrams also show that students asked a lot of explanation questions when they reached the highest conceptual understanding level (i.e., the examined level, level 4). All these features represent the key epistemic practices (i.e., the cycle of proposing, testing, and revising hypothesis) that ground scientists' processes of inquiry.

Nevertheless, research shows that students do not always see the goal of experimentation as constructing causal relations (Schauble, Glaser, Duschl, Schulze, & John, 1995). It indicates that producing consistent and coherent warranted claims is essential to help students construct scientific knowledge and foster conceptual change. This study found that students rarely check knowledge validity even though they made an effort to generate warranted claims. One possibility is that groups constructed explanations in a piecemeal way when using simulations. They filled in parts of a conversation to make partial meaning of a phenomenon, however failing to develop sound and valid explanations. This indicates that explicit epistemic scaffolding may be needed to promote high quality explanations.

Modified Collaborative Scientific Conceptual Change Model

The goals of this dissertation was to propose and test a new conceptual change model. Some modifications are needed based on the results of this middle school classroom study. The results from the MLA modeling shows that the more warranted claims the students in a group produced, the more conceptual understanding they would achieve. Consistently, the results showed that warranted claims occurred mostly at the explanatory and examined level (level 4). This confirmed the positive contribution of collaborative discourse to the collaborative scientific conceptual change. In addition, the results show sophisticated epistemic practices such as predicting and coordinating theory and evidence promote conceptual understanding. Thus the roles of epistemic practices have also been confirmed. However, the results did not support the role of cognitive conflict in the conceptual change process. Therefore, the role of knowledge discrepancy in the collaborative scientific conceptual change model was modified with less stress (see in figure 13). Compared to the previous model, the modified model deleted the arrows referring the relations between collaborative discourse, epistemic practices, and knowledge discrepancy. In addition, due to lack of the supporting data for the causal relation between knowledge discrepancy and conceptual change, the arrow between those two boxes is changed to a dashed line. The dashed line represents that knowledge discrepancy or anomalous data may not necessarily leads to conceptual change, as found in some research (Chinn & Brewer, 1993).

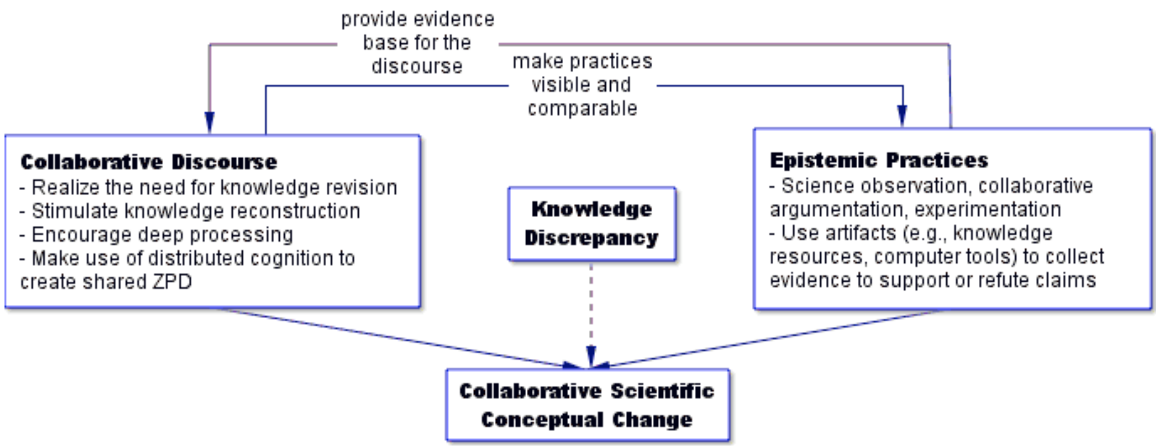

Figure 13. Revised Collaborative Scientific Conceptual Change Model based on Study Results.

Other Factors Affecting Conceptual Understanding

The results illustrate that there are other factors that affect students' conceptual understanding such as the teachers' impact. Specifically, the inquiry-based teaching style (Mr. K) stimulated more group discussion than the teacher-centered approach (Ms. W) did. In this study, Mr. K explicitly asked the students to look for patterns while running the simulations. Then they were asked to collect quantitative data and conduct several experiment trials to come up with some fashion of explanations for the observed patterns. Finally, the groups were asked to collectively reflect on their previous learning experiences and build an explanatory model to combine the collected evidence and explanations. Ms. W applied a quite different approach. She designed worksheets for each simulation model with specific questions designed to guide groups' inquiry. However, the guidance seemed to be too specific and constrained students' exploratory activities. While computer-based tools can provide extraordinary opportunities for engaging in scientific inquiry (Lee & Songer, 2003), the results indicate that orchestrating tool-mediated learning is a difficult task and has direct effect on students' trajectories of collaborative scientific conceptual change. Dunbar (1993) found that subjects who were asked to explain data, rather than verify a given hypothesis, were more systematic and designed better experiments and were thus more likely to discover the correct function of a gene. The results replicated in another study. Schauble and her colleagues found that students could design better experiments after explicit instruction that experiments are intended to isolate causal relations (Schauble, Glaser, Duschl, Schulze, & John, 1995). These results suggest that making the epistemic demands of inquiry explicit to students can improve their efforts and conceptual understanding (Sandoval, 2003).

In summary, the results of the study imply that the collaborative scientific conceptual change model is an effective framework for studying conceptual change. Specifically, a group's conceptual understanding is closely related to both collaborative discourse and epistemic practices as well as the interrelations between these two factors. In addition, the simulation environment may mediate the development of successful collaborative interactions (including collaborative discourse and epistemic practices) that lead to collaborative scientific conceptual change.

Limitations of the Study

One limitation is the variation of group members in the group due to objective difficulties in classroom studies, such as absence of students or school events, even though the error residual was randomized across groups. A second limitation lies in the quality of the video and audio data. Due to the limitation of the videotaping equipment and available personnel, only one video camera was used for each focal group, which limited the focus be either students' faces or the computer screen. In this study, most of the time, the camera was shooting the computer screen so that the researchers could capture what manipulation the students applied to the simulation models. Therefore, many nonverbal data were missing, for instance the facial expressions.

Implications for Education

As known to most educators and researchers, students cannot rely on the rote memorization of facts or the simple additive enrichment of their preconceptions to change their conceptual understanding. Instead, they need to be able to restructure their prior knowledge based on their experiences of talking and doing science. The results of this study implicate that opportunities are needed for students to experience the mechanisms of collaborative scientific conceptual change.

To successfully achieve conceptual change, students need to use the intentional and deliberate mechanisms that scientists use to restructure knowledge in a social process. These intentional mechanisms often include cycles of hypothesizing, testing hypotheses, generating theories, negotiating, and revising theories. One instructional strategy that research found promising is the Hypothesis-Experiment-Instruction method (Hatano &

Inagaki, 1991; Itakura, 1986). As Vosniadou (2007) summarized in a review of Hatano's research, this method emphasizes both talking and doing science in a sociocultural environment. Consistent with the results of this study, Hatano and colleagues believes that cognitive conflict may not be enough to create conceptual change. In order to amplify students' intentional learning, a teacher needs to create a sociocultural environment that favors "collective comprehension activities" (Hatano & Inagaki, 1991, 2003). In their studies, Hatano and colleagues used the instruction that encourage students to participate in whole-class and small group discussion. The whole-class discussion ensures that the group discussion focus on specific problems. In addition, it provides a context for groups to share and negotiate alternative solutions. Then the students can break up in small groups that compete with each other in discovering and testing alternative hypotheses and supporting it with the best arguments. This division of labor creates what Hatano calls "partisan motivation" that enhances the likelihood of conceptual change (Hatano & Inagaki, 1991, 2003).

The results of this study suggest that direct experience with scientific phenomena in the simulation-based environment helped students deeply engage in learning content through collaborative discourse and epistemic practices. Unfortunately, a consistent finding from research on students' and teachers' epistemological conceptions of science is that both teachers and students typically have naïve views of the nature of scientific knowledge and scientific work (Sandoval, Bell, Coleman, Enyedy, & Suthers, 2000). Literature shows that computer simulations can be instructional tools that focus students' conceptual and epistemological thinking in particular ways. They create a learning context supporting learner-centered scientific investigations of the natural world. The simulation-based learning environments engage students in investigational practices promoting framing research questions, designing experiments, collecting and analyzing data, and constructing causal explanation and evidence-based theories. Currently, there are various software tools available that students and teachers may use to foster the epistemological approach towards science learning as dynamic evolution (Linn, Bell, & His, 1998; Sandoval & Reiser, 2004; Suthers, Toth, & Weiner, 1997). Sandoval and colleagues suggested several design principles to develop such tools. These principles include providing epistemic forms for students' expression of their thinking, giving distinct forms of knowledge distinct representations, communicate evaluation criteria and connect them to representations.

Significance of the Dissertation and Future Research

The dissertation makes contributions in theoretical, methodological and pedagogical areas. Theoretically, it contributes to expand the theoretical base of current conceptual change theories by stressing the factors of social interactions and the epistemic practices of science. Student collaborative learning provides opportunities to articulate ideas, discover knowledge discrepancies, and revise ideas. Appropriate epistemic practices of science such as systematic observation, argumentation, and experimentation, may well guide students to construct knowledge and explain natural phenomena. Methodologically, multiple methods are employed in this study both quantitative and qualitative, including variance analyses, multilevel analysis, sequential analysis, CORDTRA analyses, and case studies. The combination of these analytical techniques is extremely useful for analyzing video data from classroom studies to address issues in unit of analysis, visualizing messy data, and repeated measures.

Pedagogically, the findings of the study illuminate approaches to supporting middle school science education and designing CSCL environments to promote collaborative scientific thinking. The proposed new conceptual change theory with its stress on investigating students' discourse and epistemic practices of science advocates such pedagogical approaches that emphasize how to foster student skills of collaborative inquiry and scientific attitudes. In addition, the findings illuminate approaches to supporting middle school science education and designing CSCL environments to promote collaborative scientific thinking.

This dissertation proposed and demonstrated how to use a new conceptual change model – the collaborative scientific conceptual change, to investigate how socioconstructivist factors including attributes in collaborative discourse and epistemic practices, affect scientific conceptual change in a CSCL learning environment. Although this dissertation has answered a lot of questions, there are still other questions unanswered, such as what specific patterns of collaborative discourse and epistemic practices occur when students improved their conceptual understanding level, how students' misconceptions evolve in CSCL contexts. In addition, further research is needed to refine the theoretical framework by addressing questions like how students' collaborative discourse and/or epistemic practice patterns evolve during the conceptual change process.

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Appendices

Appendix A: Pre- / Posttest

Name: ____

Class Period: ________________

Date: ______________

Purpose of study

We are trying to find out what you understand about aquarium ecosystems so we can design computer programs and other materials to help people learn science. You will not be graded on any of this.

Instructions

1. Answer each question carefully. Questions have to be answered in the sequence in which they are asked. Once you have answered a question move to the next question.

2. Move to the next question only after you have answered the first question to the best of your abilities.

3. Once you have moved forwards do not go back to the questions you have already answered.

Please read the questions carefully and answer as fully as you can. Remember that you are answering these questions anonymously and we really want to know what people understand about aquariums.

1. Draw all the parts of an aquarium. Please label your diagram.

2. Explain how the following elements are related to the aquarium system. Be sure to tell us everything that you know about each of them and why they are important for the aquarium.

a) Fish

b) Plants

c) Bacteria

d) Algae

e) Oxygen

f) Carbon dioxide

g) Nitrogen

h) Ammonia

i) Light

j) Heater

k) Air pump

l) Substrate

m) Food

3. What does the filter do in an aquarium? What are some properties of filters that allow them to do their job?

4. What happens if the filter breaks?

5. What kind of waste do fish produce?

6. How would you expect the fish from a lake to be different from fish in a river? Why would you see those differences?

7. How is a goldfish bowl different from an aquarium?

8. How is a lake different from an aquarium?

9. What would happen if you suddenly added 10 new fish to the 12 guppies already in a 20-gallon tank? How would that affect the systems' ability to remove ammonia from the tank?

10. In one 55-gallon tank setup, Alice has 6 angelfish, 10 of one kind of catfish and 10 of another and also another 8 fish of various types. She also has many plants in her tanks.

a) How would the conditions in the tank change if the power failed for 1 hour?

b) How would the conditions in the tank change if the power failed for 12 hours?

c) How would the chemical balance in the aquarium be affected? Why is this important?

11. Your classroom has had an aquarium up and running for several weeks. It is in the back corner of the classroom near the window. The tank holds 20 gallons of water and has 2 adult guppies, 4 baby guppies, 2 neon tetras, and 3 cory's. After a long, gray winter, the sun finally came out on Friday. After a 3-day weekend, you return Tuesday and see a green tint in the water and on the glass in the tank.

What might have caused this problem and how would you improve the conditions in the tank?

Appendix B: Work Sheet for Fish Spawning Model

Getting started

- Go to File in pull-down menu and click open
- Open the models library.
- Open the Model Fish spawn 4.1 by clicking on it
- Before you begin you can set up the model. In order to do that
    - Move the slider labeled ‘N-boy-fish’ to set the number of boy fish.
    - Move the slider labeled ‘N-girl-fish’ to set the number of girl fish.
    - Move the slider labeled ‘Filter flow’ to change the speed with which the filter cleans the water.
    - Move the slider labeled ‘Amount food’ to change the amount of food added to the system.
    - Move the slider labeled ‘p-spawn’ to change the probability of spawning (i.e. the likelihood that the fish will have babies)
    - Move the slider on the top of the model to adjust the speed with which the model proceeds.
    - Move the slider on the top of the model (‘Adjust speed slider’) and set it to the middle position. This slider controls the speed with which the model proceeds.
- Click on the ‘Startup’ button to setup the model.
- Click on ‘Go’ button to start the model and stop it.
- Once you have stopped the model, you can
    - Click on ‘Go’ button to start at the same point.
    - Click on ‘Startup’ button to setup again.
- Click on the ‘Change Water’ button anytime in order to do a water change. (When do you think you would want to do this?)

Part I.

1. Explore the model and describe what you see.

2. How does this relate to what you saw in the aquarium?

3. What kind of things can you discover about the model? What are the objects?

4. Describe the relationships among the objects in the model.

5. What kinds of questions could you ask with this model?

Part II.

1. What will happen if the number of boy-fish
   a) increases?
   b) decreases?

What is the question I am trying to answer? How does ______________________affect ___________________________?

What do I predict will happen?

What will I change?	Why will I change it?
What will I keep the same?	Why?
What will I look for?	Why?

What did you observe?

Were your predictions correct? Explain your answer.

2. What will happen if the number of girl fish
   a) increases?
   b) decreases?

What is the question I am trying to answer? How does ______________________affect ___________________________?

What do I predict will happen?

What will I change?	Why will I change it?
What will I keep the same?	Why?
What will I look for?	Why?

What did you observe?

Were your predictions correct? Explain your answer.

3. What will happen if you change the water?

Purpose: The question I am trying to answer. How does ______________________affect ___________________________?

Hypothesis: What do I predict will happen?

What will I change?	Why will I change it?
What will I keep the same?	Why?
What will I look for?	Why?

What did you observe?

Were your predictions correct? Explain your answer.

4. What will happen if you increase the filter flow?

What is the question I am trying to answer. How does ______________________affect ___________________________?

What do I predict will happen?

What will I change?	Why will I change it?

What will I keep the same?	Why?

What will I look for?	Why?

What did you observe?

Were your predictions correct? Explain your answer.

Part III

1. What is the relationship between number of fish and water quality?

2. Will increasing the probability of spawning have any effect on the water quality?

Appendix C: Work Sheet for Nitrogen Cycle Model

Getting started

- Go to File in pull-down menu and click open
- Open the models library.
- Open the Model Nitrogen cycle 6.1 by clicking on it
- Before you begin you can set up the model. In order to do that
  - Move the slider labeled 'N-Fish' to set the number of fish.
  - Move the slider labeled 'N-Plants' to set the number of plants.
  - Move the slider on the top of the model ('Adjust Speed') and set it to the middle position. This slider controls the speed with which the model proceeds.
- Click the 'Start' button to setup the model with desired number of fish and plants.
- Click on 'Go' button to start and stop the model.
- Once you have stopped the model, you can
  - Click on 'Go' button to start at the same point.
  - Click on 'Start' button to setup again.
- Click on the 'Change Water' button anytime in order to do a water change. (When do you think you would want to do this?)

Part I.

1. Explore the model and describe what you see.

2. How does this relate to what you saw in the aquarium?

3. What kind of things can you discover about the model?   What are the objects?

4. Describe the relationships among the objects in the model.

5. What kinds of questions could you ask with this model?

Part II.

1. What will happen if the number of fish
   a) increases?
   b) decreases?

What is the question I am trying to answer?
How does ______________________affect ___________________________?

What do I predict will happen?

What will I change?

Why will I change it?

What will I keep the same?

Why?

What will I look for?

Why?

What did you observe?

Were your predictions correct? Explain your answer.

2. What will happen if the number of plants
   a) increases?
   b) decreases?

Purpose: The question I am trying to answer. How does ______________________affect ___________________________?

Hypothesis: What do I predict will happen?

What will I change?	Why will I change it?
What will I keep the same?	Why?
What will I look for?	Why?

What did you observe?

Were your predictions correct? Explain your answer.

3. What will happen if you change the water?

What is the question I am trying to answer? How does ______________________affect ___________________________?

What do I predict will happen?

What will I change?	Why will I change it?
What will I keep the same?	Why?
What will I look for?	Why?

What did you observe?

Were your predictions correct? Explain your answer.

4. What do you predict will happen to the water quality graph over time?

What is the question I am trying to answer?
How does ______________________affect ___________________________?

What do I predict will happen?

What will I change?

Why will I change it?

What will I keep the same?

Why?

What will I look for?

Why?

What did you observe?

Were your predictions correct? Explain your answer.

Part III

1. What role does the nitrogen cycle play in the aquarium ecosystem?

2. What do you think will happen if you double the number of fish in your aquarium? How will you model it in the simulation?

CURRICULUM VITAE

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